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(54) **Catadioptric reduction projection optical system**

Verkleinerndes katadioptrisches Projektionssystem

Système de projection de réduction catadioptrique

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a catadioptric optical system and, more particularly, to an imaging optical system for performing reduction projection.

Related Background Art

Various optical systems for projecting and exposing a mask pattern onto a photoresist on a wafer to manufacture an integrated circuit such as an LSI have been proposed. It is known that an aberration is well corrected at a relatively large aperture in a Dyson type catadioptric optical system. However, since the imaging magnification in the Dyson type catadioptric system is unity, there is a limit in the transfer of a fine pattern.

As an optical system having a reduction factor suitable for the manufacture of a semiconductor device having a finer pattern, an optical system which is a modification of the Dyson type catadioptric optical system is disclosed in U. S. Patent 4,747,678 and U.S. Patent 4,953,960.

Although the optical system disclosed in U.S. Patent 4,747,678 which permits reduction projection allows imaging in a reduction scale having a ring-shaped view field, it basically has three concave mirrors and a convex mirror, and must be combined with a number of lenses in the use of an exposure apparatus for microlithography, resulting in a very complicated optical construction.

The reduction optical system disclosed in U.S. Patent 4,953,960 comprises a combination of a concave mirror and a lens system. Since this optical system attains reduction mainly using the concave mirror, the aberration is large, and a number of lenses must be combined to correct the aberrations.

EP-A-527,043, which is prior art only by virtue of Article 54(3) EPC, describes a catadioptric reduction projection optical system comprising a first sub-system including, in succession from the object side, a first lens group of positive refractive power and a first concave reflection mirror for forming a primary image of an object, a second optical sub-system including, in succession from the object side, a second concave reflection mirror and a third lens group of positive refractive power for re-imaging the primary image, and a second lens group of positive refractive power arranged in an optical path between the first concave reflection mirror and the second concave reflection mirror.

SUMMARY OF THE INVENTION

It would be desirable to provide a catadioptric reduction projection optical system, which has an excellent imaging performance as an optical system used in the manufacture of a semiconductor device, and has a large numerical aperture.

In accordance with the present invention there is provided a catadioptric reduction projection optical system comprising:

a first sub-system for forming a primary image I_1 of an object and including, in succession from an object side, a first lens group G_1 of positive refractive power and a first concave reflection mirror M_1, and
a second sub-system for re-imaging the primary image and including, in succession from the object side, a second lens group G_2 of positive or negative refractive power, a second concave reflection mirror M_2 and a third lens group G_3 of positive refractive power, and

wherein a magnification β_{G3} of said third lens group G_3 satisfies:

$$0.05 < \beta_{G3} < 0.6,$$

and
wherein a magnification β_{M1} of said first concave reflection mirror M_1 satisfies:

$$\beta_{M1} < -0.7.$$

In the catadioptric reduction projection optical system according to the present invention with the above construc-

tion, the first and second partial optical systems each have a concave reflection mirror having chief refractive power and a lens group (first or third lens group G_1 or G_3) of positive refractive power, and both make reduction imaging possible. Therefore, a predetermined reduction factor can be obtained as a whole system without forcing each partial optical system to bear a great burden in aberration correction. For this reason, it is possible to simplify the optical construction and yet maintain an excellent imaging performance.

A catadioptric reduction projection optical system according to one embodiment of the present invention comprises: a first partial optical system including, in succession from the object side, a first lens group G_1 of positive refractive power and a first concave reflection mirror M_1, and for forming a primary image of an object; and a second partial optical system including, in succession from the object side, a second concave reflection mirror M_2 and a third lens group G_3 of positive refractive power, and for re-imaging the primary image, wherein a second lens group G_2 of positive or negative refractive power is arranged in an optical path between the first and second concave reflection mirrors M_1 and M_2, and at least one of the first to third lens groups G_1 to G_3 is constituted by at least two different glass materials. Thus, chromatic aberration is corrected satisfactorily, and the imaging performance can be further improved.

The catadioptric reduction projection optical system according to the present invention satisfies:

$$0.05 < \beta_{G3} < 0.6 \qquad (1)$$

where β_{G3} is the magnification of the third lens group G_3 of positive refractive power. This condition defines a proper magnification of the third lens group G_3, and allows to realize a catadioptric reduction projection optical system having an excellent optical performance, and to obtain a physically constructible catadioptric reduction projection optical system. The physically constructible optical system means an optical system in which optical members do not interfere with each other in an arrangement of optical members constituting the catadioptric reduction projection optical system.

When β_{G3} exceeds the upper limit of the above-mentioned condition (1), a light beam propagating between the concave reflection mirrors M_1 and M_2 considerably overlaps a light beam propagating from the concave reflection mirror M_2 to the secondary image surface, and the arrangement of optical members constituting the catadioptric reduction projection optical system cannot be realized.

When β_{G3} is set below the lower limit of the above-mentioned condition (1), the refractive power of the third lens group G_3 increases, and coma and chromatic aberration are generated considerably.

The catadioptric reduction projection optical system according to the present invention satisfies:

$$\beta_{M1} < -0.7 \qquad (2)$$

where β_{M1} is the magnification of the first concave reflection mirror M_1. This condition defines a proper magnification of the first concave reflection mirror M_1. When β_{M1} exceeds the upper limit of the condition (2), the refractive power of the first concave reflection mirror M_1 increases, and aberrations, especially, spherical aberration and coma, generated by the first concave reflection mirror M_1 increase. In order to cancel these aberrations, the negative refractive power of a refracting optical system must be strengthened, and it becomes difficult to satisfactorily correct these aberrations.

Conversely, β_{M1} preferably satisfies the condition $-2.0 < \beta_{M1}$. When β_{M1} is set below -2.0, the refractive power of the refracting optical power must be strengthened to compensate for a decrease in refractive power of the concave reflection mirror M_1. At this time, the merits of a reflecting optical system are lost, the construction of the refracting optical system is more complicated, and it also becomes difficult to attain aberration correction.

The catadioptric reduction projection optical system according to the present invention preferably satisfies:

$$-2.5 < \beta_{M2} < -0.7 \qquad (3)$$

where β_{M2} is the magnification of the second concave reflection mirror M_2. This condition (3) defines a proper magnification of the second reflection mirror M_2. When β_{M2} exceeds the upper limit of the condition (3), the refractive power of the concave reflection mirror M_2 increases, and aberrations, especially, spherical aberration and coma, generated by the this concave reflection mirror M_2 increase. As a result, it becomes difficult to satisfactorily correct the aberrations. Furthermore, a light beam propagating toward the concave reflection mirror M_2 considerably overlaps a light beam propagating from the concave reflection mirror M_2 toward the secondary image surface, and it becomes difficult to obtain a physically constructible optical system.

When β_{M2} is set below the lower limit of the condition, the refractive power of the concave reflection mirror M_2 decreases, and the refracting optical system must compensate for the decr ase in refractive power, thus losing merits

of the reflecting optical system. At this time, the construction of the refracting optical system is more complicated, and it also becomes difficult to attain aberration correction.

The balance of aberration of the lens groups in the catadioptric reduction projection optical system according to the present invention will now be discussed. The first lens group G_1 is arranged in the vicinity of the object surface, has a function of maintaining telecentric characteristics, and corrects distortion. The second and third lens groups G_2 and G_3 contribute to formation of the reduced image and to correction of the Petzval sum. In particular, the second lens group G_2 functions as a so-called field lens, and allows a light beam from a position near the optical axis of the first concave reflection mirror M_1 to pass therethrough. Thus, the light beam through second concave mirror M_2 at a position near the optical axis and generation of aberration in the second concave reflection mirror M_2 can be prevented. The negative distortion generated in the second and third lens groups G_2 and G_3 is corrected by the positive distortion of the first lens group G_1. Lens groups (fourth and fifth lens groups G_4 and G_5) provisionally disposed in the vicinity of the concave reflection mirrors are effective to correct higher order spherical aberration generated by the concave reflection mirrors. When the concave reflection mirror is constituted to be a non-spherical mirror, since aberration generated by the concave reflection mirror is minimized, the fourth and fifth lens groups G_4 and G_5 may be omitted.

Other objects, features, and effects of the present invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows an optical path of a first embodiment according to the present invention;
Fig. 2 shows aberration of the first embodiment according to the present invention;
Fig. 3 shows an optical path of a second embodiment according to the present invention;
Fig. 4 shows aberration of the second embodiment according to the present invention;
Fig. 5 shows an optical path of a third embodiment according to the present invention;
Fig. 6 shows aberration of the third embodiment according to the present invention;
Fig. 7 shows an optical path of a fourth embodiment according to the present invention;
Fig. 8 shows aberration of the fourth embodiment according to the present invention;
Fig. 9 shows an optical path of a fifth embodiment according to the present invention;
Fig. 10 shows aberration of the fifth embodiment according to the present invention;
Fig. 11 shows an optical path of a sixth embodiment according to the present invention;
Fig. 12 shows aberration of the sixth embodiment according to the present invention;
Fig. 13 shows an optical path of a seventh embodiment according to the present invention;
Fig. 14 shows aberration of the seventh embodiment according to the present invention;
Fig. 15 shows an optical path of an eighth embodiment according to the present invention; and
Fig. 16 shows aberration of the eighth embodiment according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention will be described in detail hereinafter with reference to the accompanying drawings.

Fig. 1 is an optical path diagram showing a construction of the first embodiment according to the present invention. As shown in Fig. 1, a light beam from an object surface passes through a first lens group G_1 which comprises a biconvex positive lens L_{11}, a positive meniscus lens L_{12} having a convex surface facing the object side, and a negative meniscus lens L_{13} having a convex surface facing the object side, and has positive refractive power as a whole, and is reflected by a first concave reflection mirror M_1 having a magnification slightly smaller than unity. Then, the optical path is bent by a planar reflection mirror M_3. The first lens group G_1 mainly functions to correct distortion and to maintain telecentric characteristics. The first lens group G_1 and the first concave reflection mirror M_1 form a primary reduced image I_1.

A light beam from the primary image I_1 passes through a second lens group G_2 comprising a positive meniscus lens L_{21} having a convex surface facing the primary image side, a negative meniscus lens L_{22} having a concave surface facing the primary image side, and a biconvex positive lens L_{23}, and reaches a second concave reflection mirror M_2 having an enlargement factor via a fourth lens group G_4 having negative refractive power. The second lens group G_2 mainly functions to correct distortion and curvature of field, and functions as a field lens. The fourth lens group G_4 comprises a negative meniscus lens having a convex surface facing the second concave reflection mirror M_2 side, and functions to correct aberrations caused by the first and second concave reflection mirrors M_1 and M_2.

The light beam reflected by the second concave reflection mirror M_2 passes through the fourth lens group G_4 again, and then becomes incident on a third lens group G_3 having positive refractive power. The third lens group G_3 comprises, in succession from the incident side of a light beam, a negative meniscus lens L_{31} having a concave lens facing the incident side, a positive meniscus lens L_{32} having a convex surface facing the incident side, a positive

meniscus lens L_{33} having a convex surface facing the incident side, a biconcave negative lens L_{34}, a biconvex positive lens L_{35}, a positive meniscus lens L_{36} having a convex surface facing the incident side, and a positive meniscus lens L_{37} having a convex surface facing the incident side. The third lens group G_3 has a positive Petzval sum to cancel the function of making the Petzval sum by the first and second concave reflection mirrors M_1 and M_2 negative. The third lens group G_3 forms a second image I_2 in a larger reduction scale than that of the primary image I_1.

In the above-mentioned construction, the first lens group G_1 and the first concave reflection mirror M_1 constitute a first partial optical system, and the second concave reflection mirror M_2 and the third lens group G_3 constitute a second partial optical system. The second lens group G_2 is disposed in the optical path between the first and second concave reflection mirrors M_1 and M_2. The planar reflection mirror M_3 for bending the optical path is obliquely disposed near the first lens group G_1 at an angle of 45° with respect to an optical axis Ax_1 of the first partial optical system, so that an optical axis Ax_2 of the second partial optical system extends perpendicular to the optical axis Ax_1 of the first partial optical system. The second lens group G_2 is disposed only one side of the second partial optical system so as to focus light reflected by the first concave reflection mirror M_1 without shielding a light beam propagating toward the second concave reflection mirror M_2.

The first embodiment has a reduction factor of +0.20 or 1/5 as a whole, and achieves a numerical aperture of (N. A.) of 0.45 in a ring-shaped view field centered at an arc having a radius of 20 mm from the optical axis.

Table 1 below shows data of the first embodiment.

In Table 1, the signs of the refractive index and the plane-to-plane distance are reversed by reflection by the concave reflection mirror. The refractive index of each glass material corresponds to that at the wavelength (248 nm) of KrF. Note that the position of the planar reflection mirror M_3 for bending the optical path is omitted since it is not essential in the optical design.

Table 1

Data of First Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
	(Object Surface)	256.414	1.0000		
1	571.882	35.000	1.50890	(quartz)	L_{11}
2	-1107.127	13.569	1.0000		
3	286.383	38.000	1.50890	(quartz)	L_{12}
4	2061.034	143.443	1.0000		
5	323.826	20.000	1.50890	(quartz)	L_{13}
6	134.427	535.000	1.0000		
7	-816.864	-800.000	-1.0000		M_1
8	-435.732	-25.000	-1.50890	(quartz)	L_{21}
9	-664.126	-96.462	-1.0000		
10	231.231	-25.000	-1.50890	(quartz)	L_{22}
11	750.143	-107.120	-1.0000		
12	-622.742	-59.000	-1.50890	(quartz)	L_{23}
13	723.951	-616.105	-1.0000		
14	259.861	-25.000	-1.50890	(quartz)	G_4
15	891.669	-28.536	-1.0000		
16	537.817	28.536	1.0000		M_2
17	891.669	25.000	1.50890	(quartz)	G_4
18	259.861	602.523	1.0000		
19	-1642.894	12.745	1.50890	(quartz)	L_{31}
20	-356.710	2.000	1.0000		
21	166.981	32.465	1.50890	(quartz)	L_{32}
22	-4368.603	0.201	1.0000		
23	188.353	14.825	1.50890	(quartz)	L_{33}
24	489.910	10.157	1.0000		
25	-401.443	10.220	1.50890	(quartz)	L_{34}
26	370.153	3.669	1.0000		

Table 1 (continued)

Data of First Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
27	1112.370	53.780	1.50890	(quartz)	L_{35}
28	-387.055	0.100	1.0000		
29	106.932	70.805	1.50890	(quartz)	L_{36}
30	329.200	0.100	1.0000		
31	153.221	12.340	1.50890	(quartz)	L_{37}
32	983.363	10.000	1.0000		
33	(Image Surface)				

<Condition Corresponding Values>

$\beta_{G3} =$ 0.0761
$\beta_{M1} =$ -0.8606
$\beta_{M2} =$ -1.225

Fig. 2 shows coma for explaining the imaging performance of the first embodiment. Fig. 2 shows coma in the meridional direction at the center of the ring-shaped view field. As can be seen from Fig. 2, this embodiment maintains an excellent imaging performance.

As shown in Fig. 3, in a second embodiment according to the present invention, a light beam from the object surface passes through a first lens group G_1 which comprises a biconvex positive lens L_{11}, a positive meniscus lens L_{12} having a convex surface facing the incident side of the light beam, and a negative meniscus lens L_{13} having a convex surface facing the incident side, and has positive refractive power as a whole, and is then reflected by a first concave reflection mirror M_1 having a magnification slightly smaller than unity. The reflected light beam is deflected by a planar reflection mirror M_3 which is obliquely disposed at 45° with respect to an optical axis Ax_1 of the first lens group G_1, and then becomes incident on a second lens group G_2 of negative refractive power. The second lens group G_2 comprises, in succession from the incident side of a light beam, a negative lens L_{21} having a substantially plano-concave shape, a negative meniscus lens L_{22} having a concave surface facing the incident side, and a positive meniscus lens L_{23} having a concave surface facing the incident side, and forms a primary image I_1 as a reduced image of an object in the negative lens L_{21}.

The light beam emerging from the second lens group G_2 is reflected by a second concave reflection mirror M_2 having a magnification larger than unity via a fourth lens group G_4 of negative refractive power. The fourth lens group G_4 comprises a negative meniscus lens having a convex surface facing the second concave reflection mirror M_2. The light beam reflected by the second concave reflection mirror M_2 is deflected by a planar reflection mirror M_4, which is obliquely arranged at 45° with respect to an optical axis Ax_2 of the second lens group G_2, via the fourth lens group G_4 again, and becomes incident on a third lens group G_3 of positive refractive power. The third lens group G_3 comprises, in succession from the incident side of a light beam, a biconvex positive lens L_{31}, a negative meniscus lens L_{32} having a concave surface facing the incident side, a biconvex positive lens L_{33}, a negative meniscus lens L_{34} having a concave surface facing the incident side, a positive meniscus lens L_{35} having a concave surface facing the incident side, a negative meniscus lens L_{36} having a concave surface facing the incident side, and a positive meniscus lens L_{37} having a convex surface facing the incident side, and forms a secondary image I_2 in a larger reduction scale than that of the primary image I_1. The negative lens L_{21} in the second lens group G_2 is arranged at only one side so as not to shield a light beam passing through the first lens group G_1.

The second embodiment, as well, has a reduction factor of +0.20 or 1/5 as a whole, and achieves a numerical aperture of (N.A.) of 0.45 in a ring-shaped view field centered at an arc having a radius of 20 mm from the optical axis.

Table 2 below shows data of the second embodiment.

In Table 2, the refractive index of each glass material corresponds to that at the wavelength (193 nm) of ArF.

Table 2

Data of Second Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
	(Object Surface)	169.405	1.0000		

Table 2 (continued)

Data of Second Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
1	901.701	30.575	1.560194	(quartz)	L_{11}
2	-510.578	65.853	1.0000		
3	220.954	60.000	1.560194	(quartz)	L_{12}
4	318.898	110.000	1.0000		
5	295.985	33.350	1.560194	(quartz)	L_{13}
6	109.856	544.112	1.0000		
7	-644.876	-578.247	-1.0000		M_1
8	125.313	-20.000	-1.560194	(quartz)	L_{21}
9	-19308.942	-133.068	-1.0000		
10	285.898	-40.367	-1.560194	(quartz)	L_{22}
11	239.639	-32.560	-1.0000		
12	838.750	-48.824	-1.560194	(quartz)	L_{23}
13	270.000	-413.387	-1.0000		
14	690.339	-20.000	-1.560194	(quartz)	G_4
15	1371.252	-85.603	-1.0000		
16	769.864	85.603	1.0000		M_2
17	1371.252	20.000	1.560194	(quartz)	G_4
18	690.339	478.013	1.0000		
19	193.080	19.107	1.501375	(fluorite)	L_{31}
20	-330.493	3.128	1.0000		
21	-237.620	4.8000	1.560194	(quartz)	L_{32}
22	-404.696	0.100	1.0000		
23	84.943	25.587	1.501375	(fluorite)	L_{33}
24	-168.592	0.362	1.0000		
25	-164.717	13.099	1.560194	(quartz)	L_{34}
26	-296.532	2.263	1.0000		
27	-201.221	24.203	1.501375	(fluorite)	L_{35}
28	-184.897	0.552	1.0000		
29	-353.513	16.515	1.560194	(quartz)	L_{36}
30	-514.935	0.691	1.0000		
31	170.098	29.846	1.560194	(quartz)	L_{37}
32	642.145	6.065	1.0000		
33	(Image Surface)				

<Condition Corresponding Values>

$\beta_{G3} =$ 0.2013
$\beta_{M1} =$ -0.762
$\beta_{M2} =$ -0.974

Fig. 4 shows coma for explaining the imaging performance of the second embodiment. Fig. 4 shows coma in the meridional direction at the center of the ring-shaped view field. Note that a broken curve in Fig. 4 represents coma at 193.3 nm, a broken curve longer the curve representing coma at 193.3 nm represents coma at 192.9 nm, and a dotted curve represents coma at 193.7 nm. As can be seen from Fig. 4, the second embodiment can achieve correction of chromatic aberration within a range of ±0.4 nm at the wavelength of ArF, and maintains an excellent imaging performance.

A third embodiment of the present invention will be described below with reference to Fig. 5. Referring to Fig. 5, a light beam from the object surface passes through a first lens group G_1 which comprises a positive meniscus lens L_{11} having a concave surface facing the incident side of a light beam, a biconvex positive lens L_{12}, and a biconcave negative lens L_{13}, and has positive refractive power as a whole, and becomes incident on a first concave reflection

mirror M_1, which has a magnification slightly smaller than unity, via a fifth lens group G_5. The fifth lens group G_5 comprises a negative meniscus lens having a convex surface facing the first concave reflection mirror M_1, and functions to correct aberration generated by the first concave reflection mirror M_1 and second concave reflection mirror M_2. The light beam reflected by the first concave reflection mirror M_1 is deflected by a planar reflection mirror M_3 via the fifth lens group G_5 again, and becomes incident on a second lens group G_2 of positive refractive power.

The planar reflection mirror M_3 is obliquely arranged at 45° with respect to an optical axis Ax_1 of the first lens group G_1 in the optical path between the fifth and first lens group G_5 and G_1. The second lens group G_2 comprises a biconvex positive lens L_{21}, a biconcave negative lens L_{22}, and a positive meniscus lens L_{23} having a concave surface facing the incident side of a light beam. The light beam incident on the second lens group G_2 forms a primary image I_1 as a reduced image of an object in the negative lens L_{22}. The light beam emerging from the second lens group G_2 is deflected by a fourth planar reflection mirror M_4 which is obliquely arranged at 45° with respect to an optical axis Ax_2 of the second lens group G_2, is reflected by the second concave reflection mirror M_2 having a magnification larger than unity, and then becomes incident on a third lens group G_3 of positive refractive power. The third lens group G_3 comprises a biconvex positive lens L_{31}, a negative meniscus lens L_{32} having a convex surface facing the incident side, a positive meniscus lens L_{33} having a convex surface facing the incident side, a biconcave negative lens L_{34}, a biconvex positive lens L_{35}, a positive meniscus lens L_{36} having a convex surface facing the incident side, and a positive meniscus lens L_{37} having a convex surface facing the incident side. The third lens group G_3 forms a secondary image I_2 in a larger reduction scale than that of the primary image I_1 at the exit side thereof.

The third embodiment has a reduction factor of +0.25 or 1/4 as a whole, and achieves a numerical aperture of (N. A.) of 0.45 in a ring-shaped view field centered at an arc having a radius of 20 mm from the optical axis.

Table 3 below shows data of the third embodiment.

In Table 3, the refractive index of each glass material corresponds to that at the wavelength (248 nm) of KrF.

Table 3

Data of Third Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
	(Object Surface)	196.209	1.0000		
1	-1726.924	54.622	1.508385	(quartz)	L_{11}
2	260.643	0.100	1.0000		
3	214.288	55.000	1.508385	(quartz)	L_{12}
4	-3184.516	61.226	1.0000		
5	-634.272	15.000	1.508385	(quartz)	L_{13}
6	142.779	209.364	1.0000		
7	-324.815	20.000	1.508385	(quartz)	G_5
8	-1599.830	223.380	1.0000		
9	-537.154	-223.380	-1.0000		M_1
10	-1599.830	-20.000	-1.508385	(quartz)	G_5
11	-324.815	-355.860	-1.0000		
12	-286.947	-55.000	-1.508385	(quartz)	L_{21}
13	1629.963	-101.890	-1.0000		
14	165.609	-15.000	-1.508385	(quartz)	L_{22}
15	-750.059	-20.606	-1.0000		
16	343.901	-39.768	-1.508385	(quartz)	L_{23}
17	154.033	-630.899	-1.0000		
18	962.895	630.899	1.0000		M_2
19	149.915	32.150	1.467877	(fluorite)	L_{31}
20	-187.485	0.100	1.0000		
21	-186.839	7.000	1.508385	(quartz)	L_{32}
22	-727.375	0.100	1.0000		
23	117.358	20.864	1.508385	(quartz)	L_{33}
24	647.785	8.591	1.0000		
25	-284.413	15.450	1.508385	(quartz)	L_{34}
26	193.285	4.300	1.0000		

Table 3 (continued)

Data of Third Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
27	388.801	36.187	1.467877	(fluorite)	L_{35}
28	-216.450	0.100	1.0000		
29	113.246	19.238	1.467877	(fluorite)	L_{36}
30	459.066	0.100	1.0000		
31	221.661	33.854	1.508385	(quartz)	L_{37}
32	1502.269	15.400	1.0000		
33	(Image Surface)				

<Condition Corresponding Values>

$\beta_{G3} =$ 0.1342
$\beta_{M1} =$ -1.058
$\beta_{M2} =$ -2.008

Fig. 6 shows coma for explaining the imaging performance of the third embodiment. Fig. 6 shows coma in the meridional direction at the center of the ring-shaped view field. Note that a solid curve in Fig. 6 represents coma at 248.4 nm, an alternate long and short dashed curve represents coma at 252.4 nm, and an alternate long and two short dashed curve represents coma at 244.4 nm. As can be seen from Fig. 6, the third embodiment can achieve correction of chromatic aberration within a range of ±4 nm at the wavelength of KrF, and maintains an excellent imaging performance.

A fourth embodiment of the present invention will be described below with reference to Fig. 7. In the fourth embodiment, as shown in Fig. 7, a light beam from the object surface is incident on a first lens group G_1 of positive refractive power. In the first lens group G_1, the light beam passes through a positive meniscus lens L_{11} having a concave surface facing the incident side of a light beam, and is then deflected by a planar reflection mirror M_3 which is obliquely arranged at 45° with respect to an optical axis Ax_1 of the first lens group G_1. The deflected light beam passes through a biconvex positive lens L_{12} and a negative meniscus lens L_{13} having a convex surface facing the incident side of a light beam, and then reaches a first concave reflection mirror M_1 having a magnification slightly smaller than unity via a fifth lens group G_5 of negative refractive power. The fifth lens group G_5 comprises a negative meniscus lens having a convex surface facing the first concave reflection mirror side. The light beam reflected by the first concave reflection mirror M_1 forms a primary image I_1 as a reduced image of an object via the fifth lens group G_5 again and a second lens group G_2 of positive refractive power.

The second lens group G_2 comprises, in succession from the incident side of a light beam, a biconvex positive lens L_{21}, a negative meniscus lens L_{22} having a concave surface facing the incident side, and a positive meniscus lens L_{23} having a concave surface facing the incident side. The light beam from the primary image I_1 is reflected by a second concave reflection mirror M_2 having a magnification larger than unity. The optical path of the reflected light beam is deflected by a planar reflection mirror M_4, and the light beam then reaches a third lens group G_3 of positive refractive power. The planar reflection mirror M_4 is obliquely arranged at 45° with respect to an optical axis Ax_3 of the third lens group G_3. The third lens group G_3 comprises, in succession from the incident side of a light beam, a biconvex positive lens L_{31}, a negative meniscus lens L_{32} having a concave surface facing the incident side, a positive meniscus lens L_{33} having a convex lens facing the incident side, a biconcave negative lens L_{34}, a positive meniscus lens L_{35} having a convex surface facing the incident side, a positive meniscus lens L_{36} having a convex surface facing the incident side, and a positive meniscus lens L_{37} having a convex surface facing the incident side, and forms a secondary image I_2 in a larger reduction scale than that of the primary image I_1 at its exit side. The positive lens L_{12} and the negative lens L_{13} of the first lens group G_1 are arranged at only one side so as to allow a light beam toward the first concave reflection mirror to pass therethrough without shielding a light beam in the second lens group G_2. The second lens group G_2 is arranged at only one side so as to guide a light beam from the first concave reflection mirror M_1 without shielding a light beam in the first lens group G_1.

The fourth embodiment has a reduction factor of +0.25 or 1/4 as a whole, and achieves a numerical aperture of (N.A.) of 0.30 in a ring-shaped view field centered at an arc having a radius of 20 mm from the optical axis.

Table 4 below shows data of the fourth embodiment.

In Table 4, the refractive index of each glass material corresponds to that at the wavelength (248 nm) of KrF.

Table 4

Data of Fourth Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
	(Object Surface)	196.018	1.0000		
1	-5157.341	35.000	1.508385	(quartz)	L_{11}
2	-342.424	264.350	1.0000		
3	418.888	35.000	1.508385	(quartz)	L_{12}
4	-2971.961	0.100	1.0000		
5	479.951	35.000	1.508385	(quartz)	L_{13}
6	219.080	314.800	1.0000		
7	-194.621	18.000	1.508385	(quartz)	G_5
8	-370.491	159.400	1.0000		
9	-586.251	-159.400	-1.0000		M_1
10	-370.491	-18.000	-1.508385	(quartz)	G_5
11	-194.621	-187.600	-1.0000		
12	-275.679	35.500	-1.508385	(quartz)	L_{21}
13	507.601	-112.350	-1.0000		
14	144.909	-6.500	-1.508385	(quartz)	L_{22}
15	-700.764	-35.700	-1.0000		
16	198.506	-35.000	-1.508385	(quartz)	L_{23}
17	137.057	-793.600	-1.0000		
18	934.699	697.100	1.0000		M_2
19	167.048	23.800	1.467877	(fluorite)	L_{31}
20	-305.250	3.250	1.0000		
21	-269.515	6.500	1.508385	(quartz)	L_{32}
22	1602.279	0.100	1.0000		
23	83.085	35.000	1.467877	(fluorite)	L_{33}
24	534.963	8.000	1.0000		
25	-2442.622	28.500	1.508385	(quartz)	L_{34}
26	51.803	1.350	1.0000		
27	52.498	23.600	1.467877	(fluorite)	L_{35}
28	895.515	0.100	1.0000		
29	159.859	23.400	1.467877	(fluorite)	L_{36}
30	1657.174	0.100	1.0000		
31	216.018	7.500	1.508385	(quartz)	L_{37}
32	434.319	15.000	1.0000		
33	(Image Surface)				

<Condition Corresponding Values>

β_{G3} = 0.2035
β_{M1} = -0.8795
β_{M2} = -1.684

Fig. 8 shows coma for explaining the imaging performance of the fourth embodiment. Fig. 8 shows coma in the meridional direction at the center of the ring-shaped view field. Note that a solid curve in Fig. 8 represents coma at 248.4 nm, a broken curve represents coma at 238.4 nm, and a dotted curve represents coma at 258.4 nm. As can be seen from Fig. 8, the fourth embodiment can achieve correction of chromatic aberration within a range of ±10 nm at the wavelength of KrF, and maintains an excellent imaging performance.

A fifth embodiment of the present invention will be described below with reference to Fig. 9. In the fifth embodiment shown in Fig. 9, a second concave reflection mirror M_2 comprises a reflection mirror having a non-spherical surface. Referring to Fig. 9, a light beam from the object surface reaches a first concave reflection mirror M_1 having a magni-

fication slightly smaller than unity via a first lens group G_1 which comprises a positive meniscus lens L_{11} having a concave surface facing the incident side of a light beam, a positive meniscus lens L_{12} having a convex surface facing the incident side, a positive meniscus lens L_{13} having a convex surface facing the incident side, and a positive meniscus lens L_{14} having a convex surface facing the incident side, and has positive refractive power as a whole, and a fifth lens group G_5 of negative refractive power. The fifth lens group G_5 comprises a negative meniscus lens having a convex surface facing the first concave reflection mirror side. The light beam reflected by the first concave reflection mirror M_1 is deflected by a planar reflection mirror M_3, which is obliquely arranged at 45° with respect to an optical axis Ax_1 of the first lens group G_1, via the fifth lens group G_5 again, and then becomes incident on a second lens group G_2 of negative refractive power. The second lens group G_2 comprises a biconvex positive lens L_{21}, a biconcave negative lens L_{22}, and a positive meniscus lens L_{23} having a convex surface facing the incident side of a light beam, and forms a primary reduced image I_1 at its exit side.

The light beam from the primary image I_1 is deflected by a planar reflection mirror M_4 which is obliquely arranged at 45° with respect to an optical axis Ax_2 of the second lens group G_2, and reaches a second concave reflection mirror M_2 having a magnification larger than unity and a non-spherical shape. The light beam reflected by the second concave reflection mirror M_2 becomes incident on a third lens group G_3 of positive refractive power. The third lens group G_3 comprises a biconvex positive lens L_{31}, a biconcave negative lens L_{32}, a biconvex positive lens L_{33}, a positive meniscus lens L_{34} having a convex surface facing the incident side of a light beam, a positive meniscus lens L_{35} having a convex surface facing the incident side, a negative meniscus lens L_{36} having a convex surface facing the incident side, and a positive meniscus lens L_{37} having a convex surface facing the incident side, and forms a secondary image I_2 in a larger reduction scale than that of the primary image I_1.

The fifth embodiment has a reduction factor of +0.25 or 1/4 as a whole, and achieves a numerical aperture of (N. A.) of 0.5 in a ring-shaped view field centered at an arc having a radius of 24.25 mm from the optical axis.

Table 5 below shows data of the fifth embodiment.

In Table 5, as for the non-spherical reflection surface, only the radius of paraxial curvature is presented, and when a tangential plane at the vertex of a non-spherical surface is considered, a position, where the optical axis passes, on the tangential plane is defined as an origin, and a displacement, in the optical axis direction, of the non-spherical surface at a position of a height y on the tangential plane is represented by x with reference to the vertex of the non-spherical surface while the propagating direction of light is assumed to be the positive direction, the non-spherical surface shape is given by the following equation:

$$x = cy^2/\{1 + (1 - \kappa c^2 y^2)^{1/2}\} + C_4 y^4 + C_6 y^6 + C_8 y^8 + C_{10} y^{10}$$

where c is the curvature (the reciprocal number of the radius r of curvature) of the non-spherical surface at the vertex of the non-spherical surface, κ is a quadrics parameter, and C_4, C_6, C_8, and C_{10} are non-spherical surface coefficients.

In Table 5, the refractive index of each glass material corresponds to that at the wavelength (248 nm) of KrF.

Table 5

Fifth Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
	(Object Surface)	537.071	1.0000		
1	-13337.695	38.029	1.508385	(quartz)	L_{11}
2	-559.442	0.100	1.0000		
3	329.313	71.406	1.508385	(quartz)	L_{12}
4	4423.247	0.100	1.0000		
5	208.809	57.000	1.508385	(quartz)	L_{13}
6	247.488	54.831	1.0000		
7	889.869	50.000	1.508385	(quartz)	L_{14}
8	140.636	362.130	1.0000		
9	-277.199	15.000	1.508385	(quartz)	G_5
10	-485.421	540.415	1.0000		
11	-1017.359	-540.415	-1.0000		M_1

Table 5 (continued)

Fifth Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
12	-485.421	-15.000	-1.508385	(quartz)	G_5
13	-277.199	-326.174	-1.0000		
14	-494.427	-48.250	-1.508385	(quartz)	L_{21}
15	491.077	-38.033	-1.0000		
16	361.893	-10.000	-1.508385	(quartz)	L_{22}
17	-260.009	-40.978	-1.0000		
18	-279.421	-17.860	-1.508385	(quartz)	L_{23}
19	-543.231	-934.426	-1.0000		
20	1153.584	773.262	1.0000	(non-spherical)	M_2
21	187.601	29.381	1.467877	(fluorite)	L_{31}
22	-1450.353	6.033	1.0000		
23	-391.392	9.000	1.508385	(quartz)	L_{32}
24	179.475	3.183	1.0000		
25	213.669	29.199	1.467877	(fluorite)	L_{33}
26	-621.952	0.100	1.0000		
27	137.369	29.803	1.508385	(quartz)	L_{34}
28	458.595	0.100	1.0000		
29	135.180	28.421	1.467877	(fluorite)	L_{35}
30	268.007	0.100	1.0000		
31	121.989	16.840	1.508385	(quartz)	L_{36}
32	87.217	11.990	1.0000		
33	111.525	42.765	1.467877	(fluorite)	L_{37}
34	841.067	19.747	1.0000		
35	(Image Surface)				

<Non-spherical Surface Coefficient>

21st surface (second concave reflection mirror M_2)

κ 1.0
C_4 0.980896×10^{-10}
C_6 0.374676×10^{-15}
C_8 0.830862×10^{-21}
C_{10} 0.705084×10^{-26}

<Condition Corresponding Values>

$\beta_{G3} =$ 0.157
$\beta_{M1} =$ -0.811
$\beta_{M2} =$ -1.733

Fig. 10 shows coma of the fifth embodiment. Fig. 10 shows coma in the meridional direction at the center of the ring-shaped view field. As can be seen from Fig. 10, the fifth embodiment maintains an excellent imaging performance.

A sixth embodiment of the present invention will be described below with reference to Fig. 11. In the sixth embodiment, each of first and second concave reflection mirrors M_1 and M_2 has a non-spherical reflection surface. Referring to Fig. 11, a light beam from the object surface passes through a first lens group G_1 which comprises a biconvex positive lens L_{11}, a positive meniscus lens L_{12} having a convex surface facing the incident side of a light beam, a negative meniscus lens L_{13} having a convex surface facing the incident side, and a negative meniscus lens L_{14} having a convex surface facing the incident side, and has positive refractive power as a whole, and then reaches a first concave reflection mirror M_1 having a magnification slightly smaller than unity via a fifth lens group G_5 of negative refractive power. The

fifth lens group G_5 comprises a negative meniscus lens having a convex surface facing the first concave reflection mirror M_1 side.

The light beam reflected by the first concave reflection mirror M_1 is deflected by a planar reflection mirror M_3, which is obliquely arranged at 45° with respect to an optical axis Ax_1 of the first lens group G_1, via the fifth lens group G_5 again, and becomes incident on a second lens group G_2 of negative refractive power. The second lens group G_2 comprises a negative meniscus lens L_{21} having a convex surface facing the incident side of a light beam, a biconcave negative lens L_{22}, and a biconvex positive lens L_{23}, and forms a primary image I_1 as a reduced image of an object between the negative lens L_{22} and the positive lens L_{23}. The light beam emerging from the second lens group G_2 is deflected by a planar reflection mirror M_4, which is obliquely arranged at 45° with respect to an optical axis Ax_2 of the second lens group G_2, and reaches a second concave reflection mirror M_2 having a magnification larger than unity. The light beam reflected by the second concave reflection mirror M_2 is incident on a third lens group G_3 of positive refractive power. The third lens group G_3 comprises, in succession from the incident side of a light beam, a negative meniscus lens L_{31} having a convex surface facing the object side, a biconvex positive lens L_{32}, a positive meniscus lens L_{33} having a convex surface facing the incident side, a negative meniscus lens L_{34} having a concave surface facing the incident side, and a biconvex positive lens L_{35}, and forms a secondary image I_2 in a larger reduction scale than that of the primary image I_1 at the exit side of the third lens group G_3.

The sixth embodiment, as well, has a reduction factor of +0.25 or 1/4 as a whole, and achieves a numerical aperture of (N.A.) of 0.45 in a ring-shaped view field centered at an arc having a radius of 24.25 mm from the optical axis.

Table 6 below shows data of the sixth embodiment.

Note that the radius of curvature of each of the first and second concave reflection mirrors M_1 and M_2 shown in Table 6 is the radius of paraxial curvature, and the non-spherical surface coefficients of these first and second reflection mirrors M_1 and M_2 are separately listed. The refractive index of each glass material corresponds to that at the wavelength (248 nm) of KrF.

Table 6

Sixth Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
	(Object Surface)	414.498	1.0000		
1	8211.322	38.636	1.508385	(quartz)	L_{11}
2	-439.506	0.100	1.0000		
3	239.531	74.172	1.508385	(quartz)	L_{12}
4	1059.356	0.100	1.0000		
5	220.874	71.349	1.508385	(quartz)	L_{13}
6	192.087	28.244	1.0000		
7	9114.936	13.285	1.508385	(quartz)	L_{14}
8	135.907	347.569	1.0000		
9	-236.652	19.683	1.508385	(quartz)	G_5
10	-287.731	551.277	1.0000		
11	-1024.933	-551.277	-1.0000	(non-spherical)	M_1
12	-287.731	-19.683	-1.508385	(quartz)	G_5
13	-236.652	-314.837	-1.0000		
14	-149.845	-31.308	-1.508385	(quartz)	L_{21}
15	-137.269	-33.137	-1.0000		
16	257.207	-10.000	-1.508385	(quartz)	L_{22}
17	-315.674	-37.792	-1.0000		
18	-459.634	-27.954	-1.508385	(quartz)	L_{23}
19	431.125	-848.560	-1.0000		
20	1044.120	752.496	1.0000	(non-spherical)	M_2
21	106.792	12.000	1.508385	(quartz)	L_{31}
22	105.550	24.044	1.0000		
23	344.933	16.641	1.508385	(quartz)	L_{32}
24	-1397.225	0.100	1.0000		
25	105.435	30.284	1.508385	(quartz)	L_{33}

Table 6 (continued)

Sixth Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
26	890.603	8.066	1.0000		
27	-297.345	32.551	1.508385	(quartz)	L_{34}
28	-486.516	1.643	1.0000		
29	154.666	44.945	1.508385	(quartz)	L_{35}
30	-706.316	24.770	1.0000		
31	(Image Surface)				

<Non-spherical Surface Coefficient>

11th surface (first concave reflection mirror M_1)

κ 1.0
C_4 $-0.395493 \times 10^{-12}$
C_6 $-0.168923 \times 10^{-16}$
C_8 $-0.338178 \times 10^{-22}$
C_{10} $-0.134005 \times 10^{-26}$

20th surface (second concave reflection mirror M_2)

κ 1.0
C_4 0.340990×10^{-10}
C_6 0.116056×10^{-15}
C_8 0.245212×10^{-21}
C_{10} 0.260273×10^{-26}

<Condition Corresponding Values>

$\beta_{G3} =$ 0.238
$\beta_{M1} =$ -0.800
$\beta_{M2} =$ -1.357

Fig. 12 shows coma of the sixth embodiment. Fig. 12 shows coma in the meridional direction at the center of the ring-shaped view field. As can be seen from Fig. 12, the sixth embodiment maintains an excellent imaging performance.

A seventh embodiment of the present invention will be described below with reference to Fig. 13. Referring to Fig. 13, a light beam from the object surface emerges from a first lens group G_1 which comprises a biconvex positive lens L_{11}, a positive meniscus lens L_{12} having a convex surface facing the incident side of a light beam, a positive meniscus lens L_{13} having a convex surface facing the incident side of a light beam, and a negative meniscus lens L_{14} having a convex surface facing the incident side, and has positive refractive power as a whole, and is deflected by a planar reflection mirror M_3 which is obliquely arranged at 45° with respect to an optical axis Ax_1 of the first lens group G_1. The deflected light beam reaches a first concave reflection mirror M_1 having a magnification slightly smaller than unity via a fifth lens group G_5 of negative refractive power. The fifth lens group G_5 comprises a negative meniscus lens having a convex surface facing the first concave reflection mirror M_1. The light beam reflected by the first concave reflection mirror M_1 is incident on a second lens group G_2 of negative refractive power via the second lens group G_5 again. The second lens group G_2 comprises a negative meniscus lens L_{21} having a convex surface facing the incident side of a light beam, a biconcave negative lens L_{22}, a positive meniscus lens L_{23} having a concave surface facing the incident side, and a positive meniscus lens L_{24} having a concave surface facing the incident side, and forms a primary image I_1 as a reduced image of an object in the optical path between the negative lenses L_{21} and L_{22}. Note that the negative lens L_{21} in the second lens group is arranged at only one side of the optical axis Ax_2 so as not to shield the optical path extending from the first lens group G_1 toward the first concave reflection mirror M_1.

The light beam emerging from the second lens group G_2 is deflected by a planar reflection mirror M_4 which is obliquely arranged at 45° with respect to the optical axis Ax_2 of the second lens group G_2, is reflected by a second concave reflection mirror M_2 having a magnification larger than unity, and then becomes incident on a third lens group

G_3 of positive refractive power. The third lens group G_3 comprises a negative meniscus lens L_{31} having a convex surface facing the incident side of a light beam, a biconvex positive lens L_{32}, a positive meniscus lens L_{33} having a convex surface facing the incident side, a biconcave negative lens L_{34}, and a biconvex positive lens L_{35}, and forms a secondary image I_2 in a larger reduction scale than that of the primary image I_1.

The seventh embodiment has a reduction factor of +0.25 or 1/4 as a whole, and achieves a numerical aperture of (N.A.) of 0.4 in a ring-shaped view field centered at an arc having a radius of 25 mm from the optical axis.

Table 7 below shows data of the seventh embodiment.

In Table 7, the refractive index of each glass material corresponds to that at the wavelength (193 nm) of ArF.

Table 7

Seventh Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
	(Object Surface)	298.019	1.0000		
1	4860.661	33.000	1.501375	(fluorite)	L_{11}
2	-410.727	0.100	1.0000		
3	202.797	73.000	1.501375	(fluorite)	L_{12}
4	221.645	12.851	1.0000		
5	189.285	33.370	1.501375	(fluorite)	L_{13}
6	308.080	19.873	1.0000		
7	942.449	50.409	1.560194	(quartz)	L_{14}
8	133.378	326.305	1.0000		
9	-409.199	21.087	1.501375	(fluorite)	G_5
10	-618.117	538.975	1.0000		
11	-918.138	-538.975	-1.0000		M_1
12	-618.117	-21.087	-1.501375	(fluorite)	G_5
13	-409.199	-230.534	-1.0000		
14	-124.583	-16.666	-1.501375	(fluorite)	L_{21}
15	-122.761	-99.533	-1.0000		
16	139.122	-17.104	-1.501375	(fluorite)	L_{22}
17	-708.717	-35.132	-1.0000		
18	253.980	-28.131	-1.501375	(fluorite)	L_{23}
19	225.928	-6.072	-1.0000		
20	14003.190	-33.317	-1.560194	(quartz)	L_{24}
21	290.144	-904.186	-1.0000		
22	1085.235	804.185	1.0000		M_2
23	95.505	18.738	1.560194	(quartz)	L_{31}
24	92.560	23.254	1.0000		
25	1178.101	22.112	1.501375	(fluorite)	L_{32}
26	-788.023	0.100	1.0000		
27	86.141	27.769	1.501375	(fluorite)	L_{33}
28	734.979	1.972	1.0000		
29	-322.980	43.543	1.560194	(quartz)	L_{34}
30	926.558	0.100	1.0000		
31	125.704	23.783	1.501375	(fluorite)	L_{35}
32	-725.241	15.000	1.0000		
33	(Image Surface)				

<Condition Corresponding Values>

$\beta_{G3} =$ 0.373
$\beta_{M1} =$ -0.814
$\beta_{M2} =$ -0.993

Fig. 14 shows coma of the seventh embodiment. Fig. 14 shows coma in the meridional direction at the center of the ring-shaped view field. Note that a solid curve in Fig. 14 represents coma at 193.3 nm, a broken curve represents coma at 193.7 nm, and a dotted curve represents coma at 192.9 nm. As can be seen from Fig. 14, the seventh embodiment can achieve correction of chromatic aberration within a range of ±0.4 nm at the wavelength of ArF, and maintains an excellent imaging performance.

An eighth embodiment of the present invention will be described below with reference to Fig. 15. Referring to Fig. 15, a light beam from the object surface passes through a first lens group G_1 which comprises a biconvex positive lens L_{11}, a biconvex positive lens L_{12}, a negative meniscus lens L_{13} having a convex surface facing the incident side of a light beam, and a biconcave negative lens L_{14}, and which has positive refractive power as a whole, and is then deflected by a planar reflection mirror M_3 which is obliquely arranged at 45° with respect to an optical axis Ax_1 of the first lens group G_1. The deflected light beam reaches a first concave reflection mirror M_1 having a magnification slightly smaller than unity via a fifth lens group G_5 of negative refractive power. The fifth lens group G_5 comprises a negative meniscus lens having a convex surface facing the first concave reflection mirror M_1 side. The light beam reflected by the first concave reflection mirror M_1 is incident on a second lens group G_2 of negative refractive power via the fifth lens group G_5 again. The second lens group G_2 comprises a negative meniscus lens L_{21} having a convex surface facing the incident side of a light beam, a negative meniscus lens L_{22} having a concave surface facing the incident side, a negative meniscus lens L_{23} having a concave surface facing the incident side, and a biconvex positive lens L_{24}, and forms a primary reduced image I_1 between the negative lenses L_{21} and L_{22}.

The light beam emerging from the second lens group G_2 is deflected by a planar reflection mirror M_4 which is obliquely arranged at 45° with respect to an optical axis Ax_2 of the second lens group G_2, is reflected by a second concave reflection mirror M_2 having a magnification larger than unity, and then becomes incident on a third lens group G_3 of positive refractive power. The third lens group G_3 comprises a negative meniscus lens L_{31} having a convex surface facing the incident side of a light beam, a biconvex positive lens L_{32}, a biconvex positive lens L_{33}, a negative meniscus lens L_{34} having a concave surface facing the incident side, and a positive meniscus lens L_{35} having a convex surface facing the incident side, and forms a secondary image I_2 in a larger reduction scale than that of the primary image I_1 at its exit side.

The eighth embodiment has a reduction factor of +0.25 or 1/4 as a whole, and achieves a numerical aperture of (N.A.) of 0.4 in a ring-shaped view field centered at an arc having a radius of 24.25 mm from the optical axis.

Table 8 below shows data of the eighth embodiment.

In Table 8, the refractive index of each glass material corresponds to that at the wavelength (248 nm) of KrF.

Table 8

Eighth Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
	(Object Surface)	400.975	1.0000		
1	3191.354	33.000	1.508385	(quartz)	L_{11}
2	-448.984	15.428	1.0000		
3	223.181	64.645	1.508385	(quartz)	L_{12}
4	-4151.509	12.219	1.0000		
5	11253.765	49.299	1.508385	(quartz)	L_{13}
6	461.799	16.133	1.0000		
7	-1336.016	48.239	1.508385	(quartz)	L_{14}
8	158.062	281.551	1.0000		
9	-312.940	20.065	1.508385	(quartz)	G_5
10	-441.735	538.318	1.0000		
11	-919.752	-538.318	-1.0000		M_1
12	-441.735	-20.065	-1.508385	(quartz)	G_5
13	-312.940	-247.755	-1.0000		
14	-132.399	-22.942	-1.508385	(quartz)	L_{21}
15	-127.754	-104.702	-1.0000		
16	134.695	-14.420	-1.508385	(quartz)	L_{22}
17	11180.397	-23.490	-1.0000		
18	160.735	-29.211	-1.508385	(quartz)	L_{23}
19	163.686	-0.100	-1.0000		

Table 8 (continued)

Eighth Embodiment					
No.	Radius of Curvature	Plane-to-Plane Distance	Refractive Index		
20	1939.060	-37.447	-1.508385	(quartz)	L_{24}
21	239.738	-905.619	-1.0000		
22	1073.545	806.574	1.0000		M_2
23	89.424	16.314	1.508385	(quartz)	L_{31}
24	82.394	13.739	1.0000		
25	612.232	15.000	1.508385	(quartz)	L_{32}
26	-1320.781	0.100	1.0000		
27	86.666	25.509	1.508385	(quartz)	L_{33}
28	-1224.142	4.770	1.0000		
29	-224.139	36.310	1.508385	(quartz)	L_{34}
30	-236.345	0.589	1.0000		
31	165.225	24.171	1.508385	(quartz)	L_{35}
32	43423.922	15.000	1.0000		
33	(Image Surface)				

<Condition Corresponding Values>

β_{G3} = 0.400
β_{M1} = -0.797
β_{M2} = -0.934

Fig. 16 shows coma of the eighth embodiment. Fig. 16 shows coma in the meridional direction at the center of the ring-shaped view field. As can be seen from Fig. 16, the eighth embodiment maintains an excellent imaging performance.

In each of the above embodiments, the primary image formed by the first partial optical system (the first lens group G_1 and the first concave reflection mirror M_1) is a reduced image. However, the primary image formed by the first partial optical system is not limited to a reduced image.

In each of the above embodiments, since the optical system is constituted to satisfy the above-mentioned conditions, the optical members constituting the catadioptric reduction projection optical system do not interfere with each other. Therefore, a physically constructible catadioptric reduction projection optical system can be obtained.

In each of the second to eighth embodiments, the object surface is set to be parallel to the image surface using the two planar reflection mirrors. Thus, when the catadioptric reduction projection optical system of each of the second to eighth embodiments is adopted as an optical system of a scanning exposure apparatus, a convey mechanism for executing scanning exposure can be simplified.

The above embodiments have been described only to clarify the technical contents of the present invention, and must not be construed to limit the scope of the present invention. Therefore, various changes and modifications may be made without departing from the scope of the invention.

Claims

1. A catadioptric reduction projection optical system comprising:

   a first sub-system for forming a primary image (I_1) of an object and including, in succession from an object side, a first lens group (G_1) of positive refractive power and a first concave reflection mirror (M_1); and
   a second sub-system for re-imaging the primary image and including, in succession from the object side, a second lens group (G_2) of positive or negative refractive power, a second concave reflection mirror (M_2) and a third lens group (G_3) of positive refractive power,
   wherein a magnification β_{G3} of said third lens group (G_3) satisfies:

$$0.05 < \beta_{G3} < 0.6,$$

and

wherein a magnification β_{M1} of said first concave reflection mirror (M_1) satisfies:

$$\beta_{M1} < -0.7$$

2. A system according to claim 1, wherein the magnification β_{M1} of said first concave reflection mirror (M_1) satisfies:

$$-2.0 < \beta_{M1}$$

3. A system according to claim 1 or 2, wherein a magnification β_{M2} of said second concave reflection mirror (M_2) satisfies:

$$-2.5 < \beta_{M2} < -0.7$$

4. A system according to claim 1, 2 or 3, wherein said first sub-system forms a reduced image (I_1) of the object.

5. A system according to any of claims 1 to 4, wherein said second lens group (G_2) is constituted to direct a light from a position substantially on an optical axis of said first concave reflection mirror (M_1) to a position substantially on an optical axis of said second concave reflection mirror (M_2).

6. A system according to any of claims 1 to 5, further comprising:
   a provisional lens group (G_4, G_5) arranged in the vicinity of at least one of said first and second concave reflection mirrors (M_1, M_2).

7. A system according to claim 6, wherein said provisional lens group (G_4, G_5) has a function of correcting an aberration generated by the concave reflection mirror (M_1, M_2).

8. A system according to claim 7, wherein said provisional lens group (G_4, G_5) includes a meniscus lens component having a convex surface facing the concave reflection mirror (M_1, M_2).

9. A system according to any of claims 1 to 8, wherein a negative Petzval sum generated by said first and second concave reflection mirrors (M_1, M_2) is corrected by a positive Petzval sum generated by said third lens group (G_3).

10. A system according to any of claims 1 to 9, wherein at least one of said first and second concave reflection mirrors (M_1, M_2) has a non-spherical reflection surface.

11. A system according to any of claims 1 to 10, wherein at least one of said first to third lens groups (G_1, G_2, G_3) consists of at least two different glass materials thereby correcting chromatic aberration.

12. A system according to claim 11, wherein the at least two different glass materials include quartz glass and fluorite.

13. A system according to claim 12, wherein said first to third lens groups (G_1, G_2, G_3) consist of quartz glass and fluorite.

14. A system according to any of claims 1 to 10, wherein said first to third lens groups (G_1, G_2, G_3) consist of at least one of quartz glass and fluorite.

15. A system according to claim 14, wherein said first to third lens groups (G_1, G_3) consist of quartz glass.

16. A system according to any of claims 1 to 15, further comprising:
   at least two planar reflection mirrors (M_3, M_4), which make an image surface (I_2) parallel to an object surface.

17. A system according to claim 16, wherein one of said at least two planar mirrors (M_3) is arranged in an optical path between the object surface and the primary image (I_1), and
   the planar reflection mirror (M_4) different from said one planar reflection mirror (M_3) is arranged in an optical

path between the primary image (I_1) and the image surface (I_2).

18. A system according to any of claims 1 to 17, wherein said first lens group (G_1) includes, in succession from the object side, a lens component (L_{11}, L_{12}, L_{13}) of positive refractive power, and a lens component (L_{13}, L_{14}) of negative refractive power.

19. A system according to claim 18, wherein said lens component (L_{11}) of the positive refractive power, which component is arranged closest to the object side, is constituted so that a concave lens surface faces the object surface side.

20. A system according to any of claims 1 to 19, wherein said second lens group (G_2) includes, in succession from a light incidence side, a lens component (L_{21}, L_{22}, L_{23}) of negative refractive power and a lens component (L_{23}, L_{24}) of positive refractive power.

21. A system according to any of claims 1 to 20, wherein said third lens group (G_3) includes, in succession from a light incidence side, a negative lens component (L_{31}, L_{32}), a positive lens component (L_{32}, L_{33}, L_{34}, L_{35}), a negative lens component (L_{34}, L_{36}), and a positive lens component (L_{35}, L_{36}, L_{37}).

22. A system according to claim 21, wherein said positive lens component (L_{32}) located closest to the object side in said third lens group (G_3) has a convex lens surface facing the light incidence side.

23. A system according to claim 1, wherein at least one of said first and second lens groups (G_1, G_2) is arranged on one side of an optical axis.

24. A system according to claim 1 having a ring-shaped view field.

Patentansprüche

1. Verkleinerndes katadioptrisches Projektionssystem, umfassend:

   - ein erstes Subsystem zum Bilden eines Primärbildes (I_1) eines Objekts und - von der Objektseite hintereinander - umfassend eine erste Linsengruppe (G_1) mit positiver Brechkraft und einen ersten konkaven Reflexionsspiegel (M_1); und
   - ein zweites Subsystem zur Neuabbildung des Primärbildes, und - von der Objektseite her aufeinanderfolgend - umfassend eine zweite Linsengruppe (G_2) positiver oder negativer Brechkraft, einen zweiten konkaven Reflexionsspiegel (M_2) und eine dritte Linsengruppe (G_3) positiver Brechkraft,

   wobei die Vergrößerung β_{G3} der dritten Linsengruppe (G_3) der Bedingung genügt:

   $$0{,}05 < \beta_{G3} < 0{,}6,$$

   und
   wobei die Vergrößerung β_{M1} des ersten konkaven Reflexionsspiegels (M_1) die Bedingung erfüllt:

   $$\beta_{M1} < -0{,}7.$$

2. System nach Anspruch 1, bei dem
   die Vergrößerung β_{M1} des ersten konkaven Reflexionsspiegels (M_1) die Bedingung erfüllt:

   $$-2{,}0 < \beta_{M1}.$$

3. System nach Anspruch 1 oder 2, bei dem
   die Vergrößerung β_{M2} des zweiten konkaven Reflexionsspiegels (M_2) die Bedingung erfüllt:

$$-2{,}5 < \beta_{M2} < -0{,}7.$$

4. System nach Anspruch 1, 2 oder 3, bei dem das erste Subsystem ein verkleinertes Bild (I_1) des Objekts erzeugt.

5. System nach einem der Ansprüche 1 bis 4, bei dem die zweite Linsengruppe (G_2) derart ausgebildet ist, daß sie Licht von einer im wesentlichen auf der optischen Achse des ersten konkaven Reflexionsspiegels (M_1) liegenden Stelle auf eine Stelle lenkt, die sich im wesentlichen auf der optischen Achse des zweiten konkaven Reflexionsspiegels (M_2) befindet.

6. System nach einem der Ansprüche 1 bis 5, weiterhin umfassend:

   - eine Hilfs-Linsengruppe (G_4, G_5), die in der Nähe mindestens eines der beiden konkaven Reflexionsspiegel (M_1, M_2) angeordnet ist.

7. System nach Anspruch 6, bei dem die Hilfs-Linsengruppe (G_4, G_5) die Funktion hat, eine von dem konkaven Reflexionsspiegel (M_1, M_2) hervorgerufene Aberration zu korrigieren.

8. System nach Anspruch 7, bei dem die Hilfs-Linsengruppe (G_4, G_5) eine Meniskuslinsenkomponente mit einer dem konkaven Reflexionsspiegel (M_1, M_2) zugewandten konvexen Fläche enthält.

9. System nach einem der Ansprüche 1 bis 8, bei dem die vom ersten und zweiten konkaven Reflexionsspiegel (M_1, M_2) gebildete negative Petzval-Summe korrigiert wird durch eine positive Petzval-Summe, die von der dritten Linsengruppe (G_3) erzeugt wird.

10. System nach einem der Ansprüche 1 bis 9, bei dem zumindest einer von erstem und zweitem konkavem Reflexionsspiegel (M_1, M_2) eine asphärische Reflexionsfläche besitzt.

11. System nach einem der Ansprüche 1 bis 10, bei dem zumindest eine der ersten bis dritten Linsengruppe (G_1, G_2, G_3) aus mindestens zwei unterschiedlichen Glasmaterialien besteht, um dadurch chromatische Aberration zu korrigieren.

12. System nach Anspruch 11, bei dem die mindestens zwei verschiedenen Glasmaterialien Quarzglas und Fluorid enthalten.

13. System nach Anspruch 12, bei dem die erste bis dritte Linsengruppe (G_1, G_2, G_3) aus Quarzglas und Fluorid bestehen.

14. System nach einem der Ansprüche 1 bis 10, bei dem die erste bis dritte Linsengruppe (G_1, G_2, G_3) aus zumindest einem der Materialien Quarzglas und Fluorid bestehen.

15. System nach Anspruch 14, bei dem die erste bis dritte Linsengruppe (G_1, G_3) aus Quarzglas bestehen.

16. System nach einem der Ansprüche 1 bis 15, weiterhin umfassend:

   - mindestens zwei planare Reflexionsspiegel (M_3, M_4), die eine Bildfläche (I_2) parallel zu einer Objektfläche machen.

17. System nach Anspruch 16, bei dem

   - einer (M_3) der planaren Reflexionsspiegel im optischen Weg zwischen Objektfläche und Primärbild (I_1) angeordnet ist, und
   - ein anderer (M_4) der planaren Reflexionsspiegel im optischen Weg zwischen Primärbild (I_1) und Bildfläche

(I_2) angeordnet ist.

18. System nach einem der Ansprüche 1 bis 17, bei dem die erste Linsengruppe (G_1) - von der Objektseite her hintereinander - eine Linsenkomponente (L_{11}, L_{12}, L_{13}) positiver Brechkraft und eine Linsenkomponente (L_{13}, L_{14}) negativer Brechkraft beinhaltet.

19. System nach Anspruch 18, bei dem die Linsenkomponente (L_{11}) positiver Brechkraft, welche am dichtesten auf der Objektseite angeordnet ist, eine der Objektfläche zugekehrte konkave Linsenfläche aufweist.

20. System nach einem der Ansprüche 1 bis 19, bei dem die zweite Linsengruppe (G_2) - nacheinander von de Lichteinfallseite her - eine Linsenkomponente (L_{21}, L_{22}, L_{23}) negativer Brechkraft und eine Linsenkomponente (L_{23}, L_{24}) positiver Brechkraft enthält.

21. System nach einem der Ansprüche 1 bis 20, bei dem die dritte Linsengruppe (G_3) - nacheinander von der Lichteinfallseite her - eine negative Linsenkomponente (L_{31}, L_{32}), eine positive Linsenkomponente (L_{32}, L_{33}, L_{34}, L_{35}), eine negative Linsenkomponente (L_{34}, L_{36}) und eine positive Linsenkomponente (L_{35}, L_{36}, L_{37}) enthält.

22. System nach Anspruch 21, bei dem die positive Linsenkomponente (L_{32}), die sich innerhalb der dritten Linsengruppe (G_3) am dichtesten an der Objektseite befindet, eine konvexe Linsenfläche aufweist, die der Lichteinfallseite zugewandt ist.

23. System nach Anspruch 1, bei dem zumindest einer der ersten und der zweiten Linsengruppe (G_1, G_2) auf einer Seite einer optischen Achse angeordnet ist.

24. System nach Anspruch 1 mit einem ringförmigen Gesichtsfeld.

Revendications

1. Système optique de projection catadioptrique avec réduction comprenant :

   un premier sous-système servant à former une image primaire (I_1) d'un objet et comprenant, successivement à partir d'un côté objet, un premier groupe de lentilles (G_1) possédant un pouvoir réfringent positif et un premier miroir réfléchissant concave (M_1) ; et
   un second sous-système pour reformer l'image primaire et comprenant, successivement à partir du côté objet, un second groupe de lentilles (G_2) ayant un pouvoir réfringent positif ou négatif, un second miroir réfléchissant concave (M_2) et une troisième groupe de lentilles (G_3) ayant un pouvoir réfringent positif,

   dans lequel un grandissement β_{G3} dudit troisième groupe de lentilles (G_3) satisfait à :

$$0,05 < \beta_{G3} < 0,6,$$

   et
   et dans lequel un grandissement β_{M1} dudit premier miroir réfléchissant concave (M_1) satisfait à :

$$\beta_{M1} < -0,7$$

2. Système selon la revendication 1, dans lequel le grandissement β_{M1} dudit premier miroir réfléchissant concave (M_1) satisfait à :

$$-2,0 < \beta_{M1}$$

3. Système selon la revendication 1 ou 2, dans lequel un grandissement β_{M2} dudit second miroir réfléchissant concave (M_2) satisfait :

$$-2{,}5 < \beta_{M2} < -0{,}7$$

4. Système selon la revendication 1, 2 ou 3, caractérisé en ce que ledit premier sous-système forme une image réduite (I_1) de l'objet.

5. Système selon l'une des revendications 1 à 4, dans lequel ledit second groupe de lentilles (G_2) est situé de manière à diriger une lumière depuis une position située sensiblement sur un axe optique dudit premier miroir réfléchissant concave (M_1) vers une position située sensiblement sur un axe optique dudit second miroir réfléchissant concave (M_2).

6. Système selon l'une quelconque des revendications 1 à 5, comprenant en outre :
   un groupe de lentilles provisoires (G_4, G_5) disposé au voisinage d'au moins l'un desdits premier et second miroirs réfléchissants concaves (M_1, M_2).

7. Système selon la revendication 6, dans lequel le groupe de lentilles provisoires (G_4, G_5) a pour rôle de corriger une aberration produite par le miroir réfléchissant concave (M_1, M_2).

8. Système selon la revendication 7, dans lequel ledit groupe de lentilles provisoires (G_4, G_5) comprend un composant de lentille en forme de ménisque possédant une surface convexe tournée vers le miroir réfléchissant concave (M_1, M_2).

9. Système selon l'une quelconque des revendications 1 à 8, dans lequel une somme négative de Petzval produite par lesdits premier et second miroirs réfléchissants concaves (M_1, M_2) est corrigée par une somme de Petzval positive produite par ledit troisième groupe de lentilles (G_3).

10. Système selon l'une quelconque des revendications 1 à 9, dans lequel au moins l'un desdits premier et second miroirs réfléchissants concaves (M_1, M_2) possède une surface réfléchissante non sphérique.

11. Système selon l'une quelconque des revendications 1 à 10, dans lequel au moins l'un desdits premier à troisième groupes de lentilles (G_1, G_2, G_3) est constitué par au moins deux verres différents, ce qui permet de corriger une aberration chromatique.

12. Système selon la revendication 11, dans lequel les au moins deux verres différents comprennent du verre quartzeux et du verre fluoré.

13. Système selon la revendication 12, dans lequel lesdits premier à troisième groupes de lentilles (G_1, G_2, G_3) sont constitués par du verre quartzeux et du verre fluoré.

14. Système selon l'une quelconque des revendications 1 à 10, dans lequel lesdits premier à troisième groupes de lentilles (G_1, G_2, G_3) sont constitués par au moins l'un d'un verre quartzeux et d'un verre fluoré.

15. Système selon la revendication 14, dans lequel lesdits premier à troisième groupes de lentilles (G_1, G_3) sont constitués de verre quartzeux.

16. Système selon l'une quelconque des revendications 1 à 15, comprenant en outre :
   au moins deux miroirs réfléchissants plans (M_3, M_4), qui forment une surface d'image (I_2) parallèle à une surface de l'objet.

17. Système selon la revendication 16, dans lequel l'un desdits au moins deux miroirs plans (M_3) est disposé dans un trajet optique entre la surface de l'objet et l'image primaire (I_1), et
   le miroir plan réfléchissant (M_4) différent dudit un miroir plan réfléchissant (M_3) est disposé dans un trajet optique entre l'image primaire (I_1) et la surface (I_2) d'image.

18. Système selon l'une quelconque des revendications 1 à 17, dans lequel ledit premier groupe de lentilles (G_1)

comprend, successivement à partir du côté objet, un composant de lentille (L_{11}, L_{12}, L_{13}) ayant un pouvoir réfringent positif, et un composant de lentille (L_{13}, L_{14}) ayant un pouvoir réfringent négatif.

19. Système selon la revendication 21, dans lequel ledit composant de lentille (L_{11}) possédant le pouvoir réfringent positif, qui le plus proche du côté objet, est constitué de telle sorte qu'une surface concave de lentille est tournée vers le côté de la surface de l'objet.

20. Système selon l'une quelconque des revendications 1 à 19, dans lequel ledit second groupe de lentilles (G_2) comprend successivement à partir d'un côté d'incidence de la lumière, un composant de lentille (L_{21}, L_{22}, L_{23}) possédant un pouvoir réfringent négatif et un composant de lentille (L_{23}, L_{24}) ayant un pouvoir réfringent positif.

21. Système selon l'une quelconque des revendications 1 à 20, dans lequel ledit troisième groupe de lentilles (G_3) comprend, successivement à partir d'un côté d'incidence de la lumière, un composant de lentille négatif (L_{31}, L_{32}), un composant de lentille positif (L_{32}, L_{33}, L_{34}, L_{35}), un composant de lentille négatif (L_{34}, L_{36}) et une composant de lentille positif (L_{35}, L_{36}, L_{37}).

22. Système selon la revendication 21, dans lequel ledit composant de lentille positif (L_{32}), qui est situé le plus près du côté objet dans ledit troisième groupe de lentilles (G_3), possède une surface de lentille convexe tournée le côté d'incidence de la lumière.

23. Système selon la revendication 1, dans lequel au moins l'un desdits premier et second groupes de lentilles (G_1, G_2) est disposé d'un côté d'un axe optique.

24. Système selon la revendication 1, possédant un champ d'observation de forme annulaire.

FIG. 1

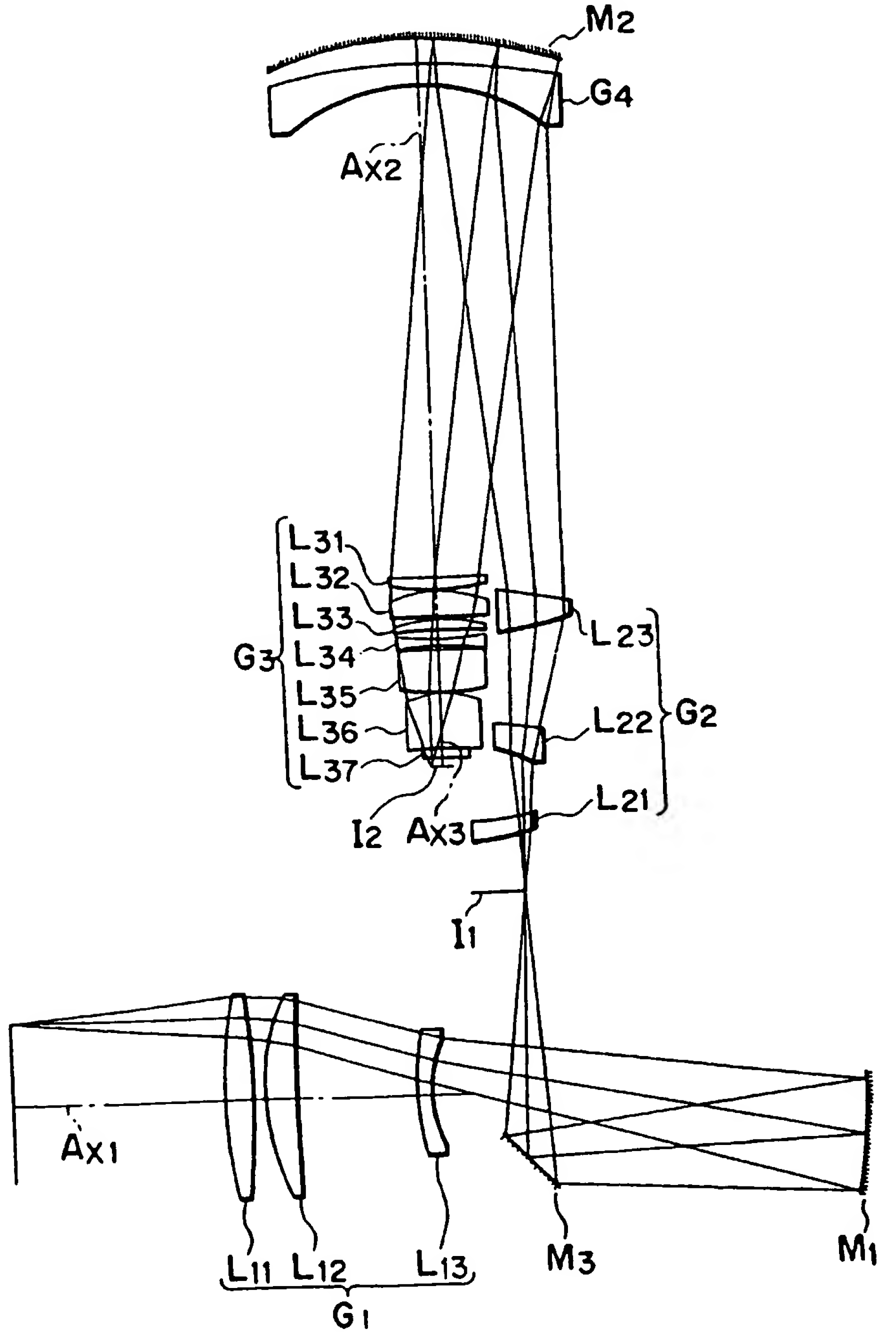

M2
G4
Ax2
L31
L32
L33
L34
L35
L36
L37
G3
L23
L22
L21
G2
I2
Ax3
I1
Ax1
L11
L12
L13
G1
M3
M1

FIG. 2

COMA

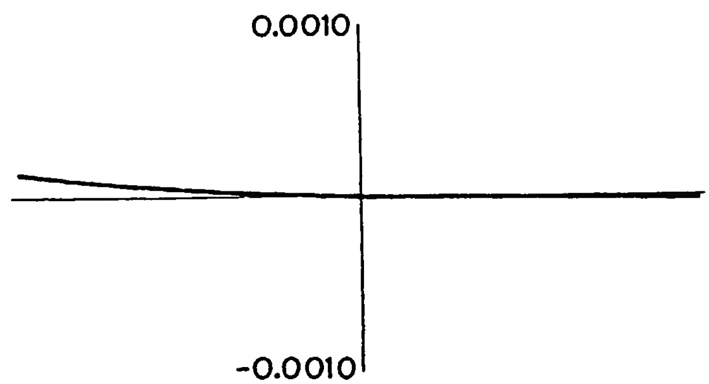
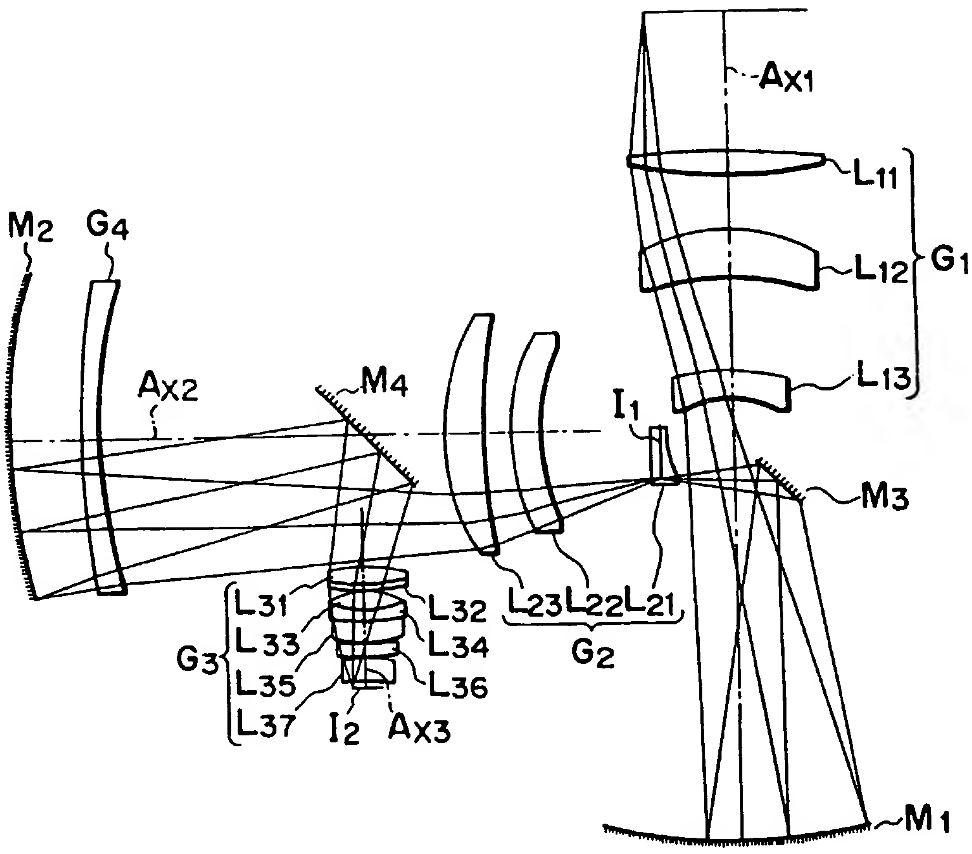


FIG. 3



Ax1
L11
L12
G1
L13
M2
G4
Ax2
M4
I1
M3
L31
L32
L33
L34
G3
L35
L36
L37
I2
Ax3
L23
L22
L21
G2
M1

FIG. 4

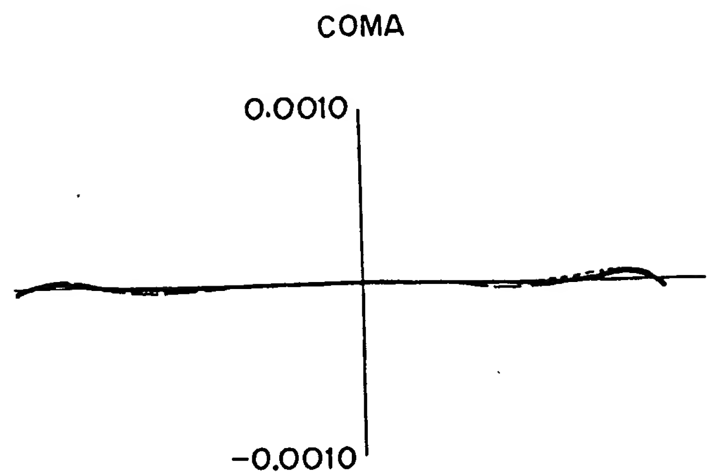


FIG. 5

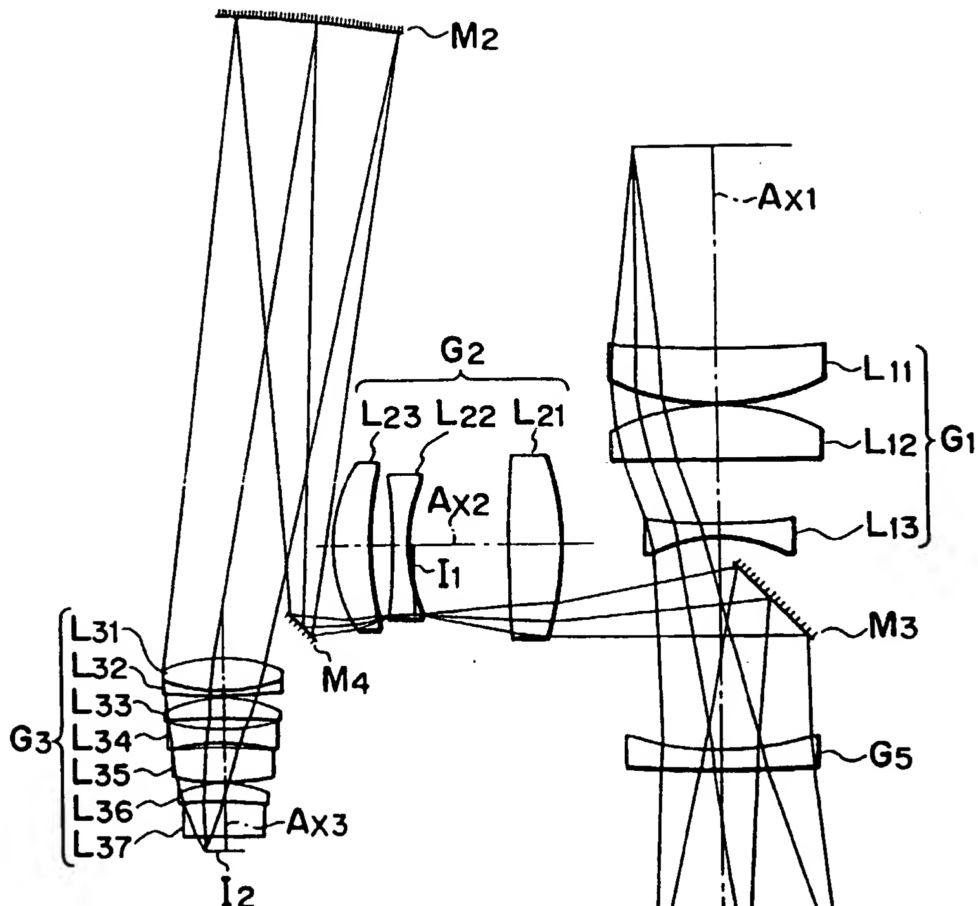

M2
Ax1
G2
L23 L22 L21
Ax2
I1
L11
L12
G1
L13
M3
M4
L31
L32
L33
G3
L34
L35
L36
L37
Ax3
I2
G5
M1

FIG. 6

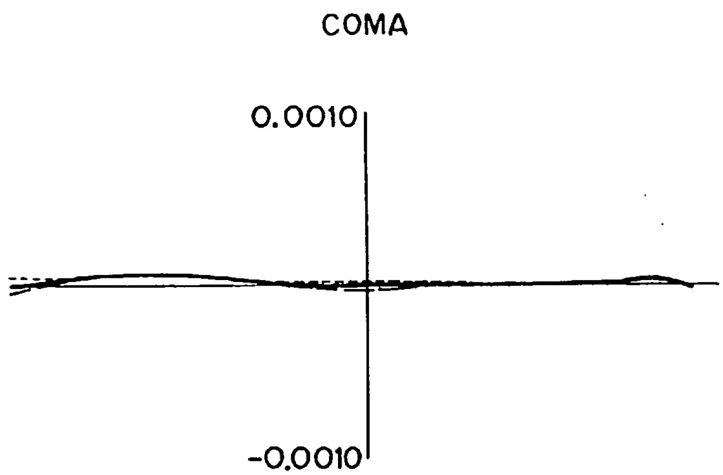


FIG. 7

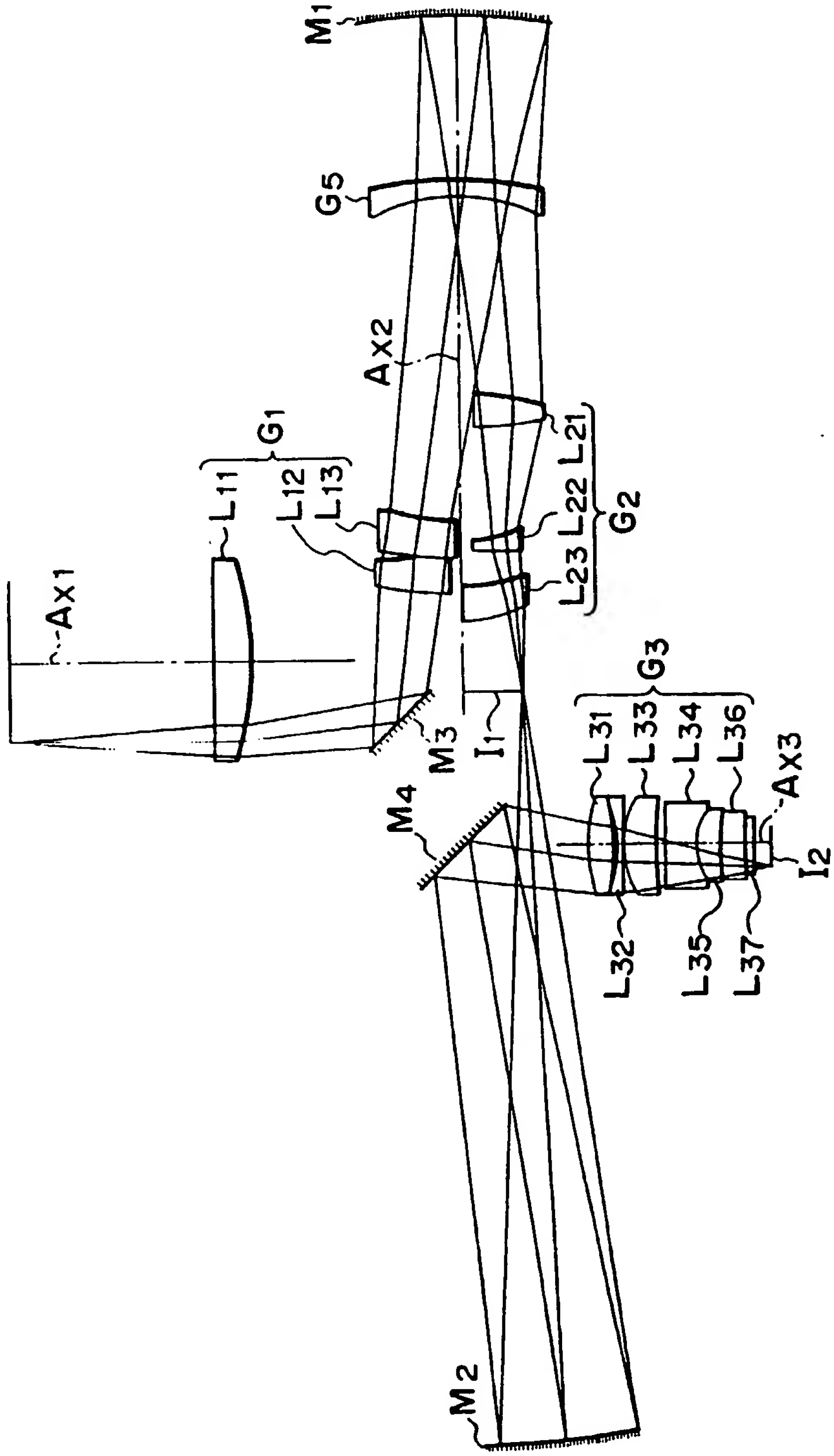

M_1
G_5
A_{X2}
G_1
L_{11}
L_{12}
L_{13}
L_{21}
L_{22}
L_{23}
G_2
A_{X1}
M_3
I_1
G_3
L_{31}
L_{33}
L_{34}
L_{36}
A_{X3}
M_4
I_2
L_{32}
L_{35}
L_{37}
M_2

FIG. 8

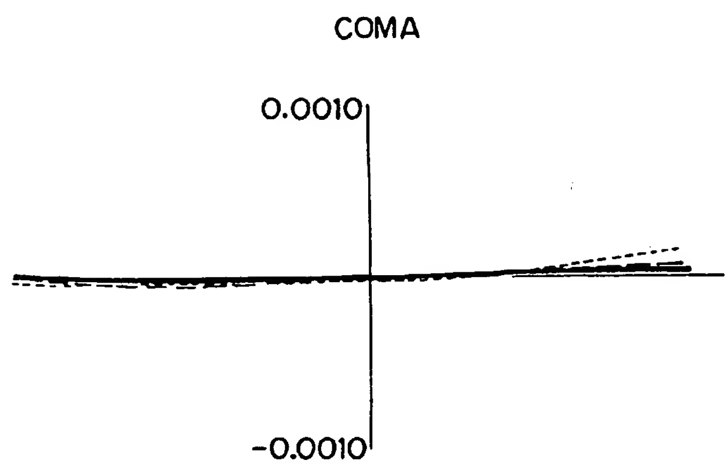


FIG. 9

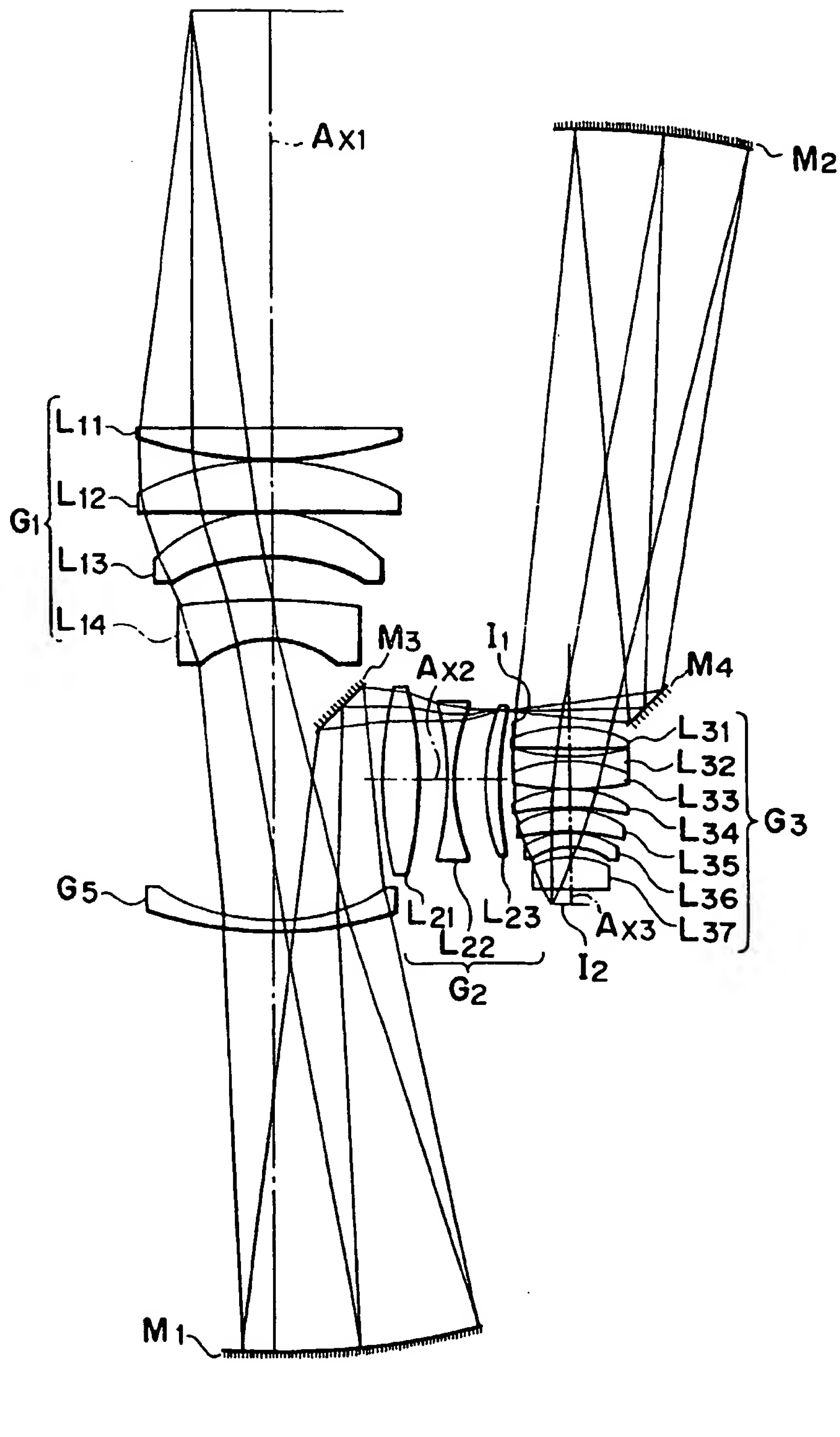

Ax1
M2
L11
L12
G1
L13
L14
M3
I1
Ax2
M4
L31
L32
L33
L34
G3
L35
L36
G5
L21
L23
Ax3
L37
L22
I2
G2
M1

FIG. 10

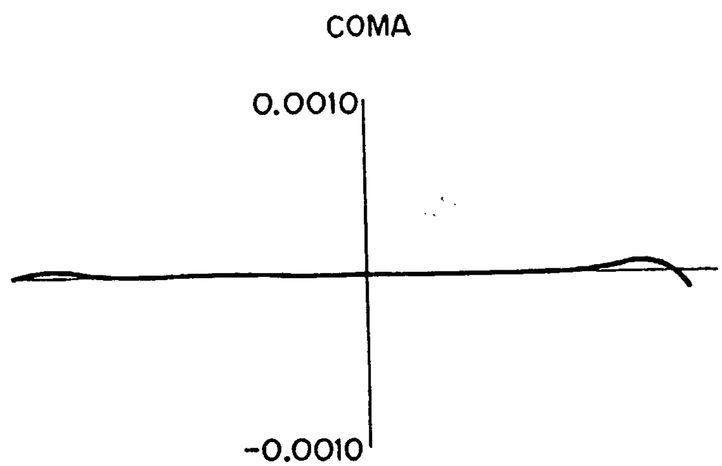
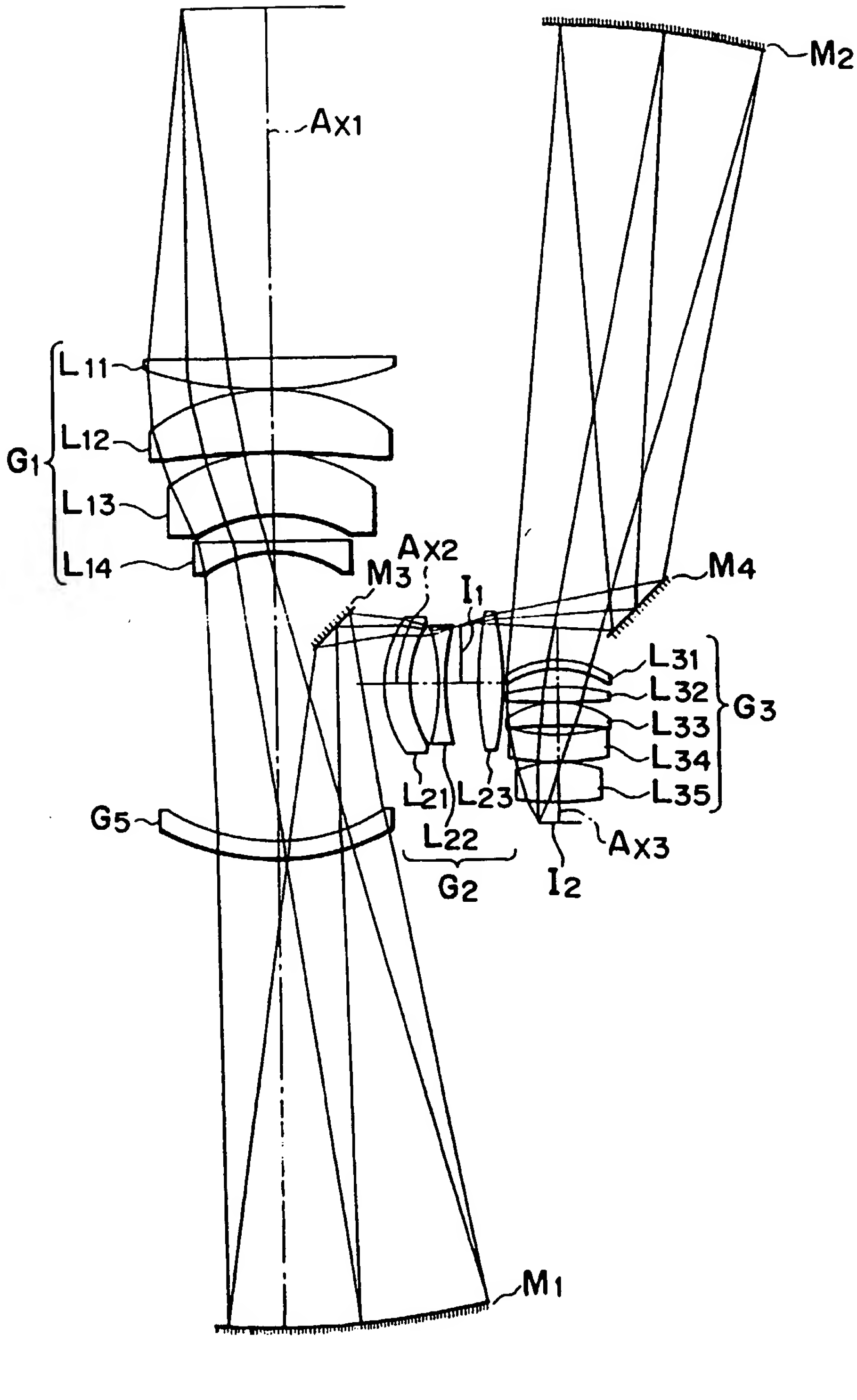


FIG. 11



M2
Ax1
L11
L12
G1
L13
L14
Ax2
M3
I1
M4
L31
L32
G3
L33
L34
L35
L21
L23
G5
L22
Ax3
G2
I2
M1

FIG. 12

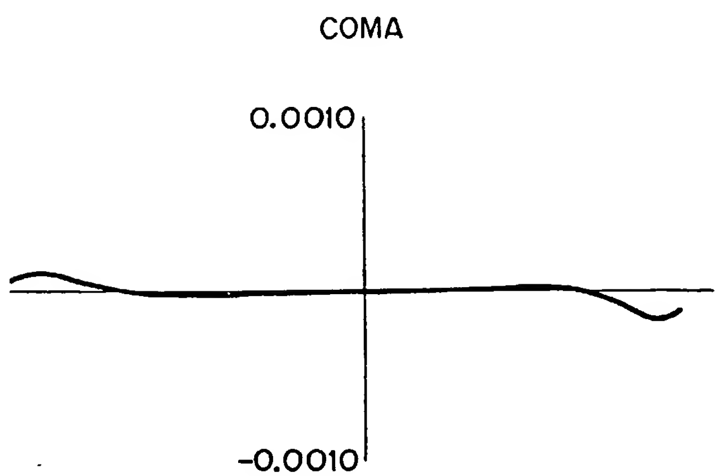


FIG.13

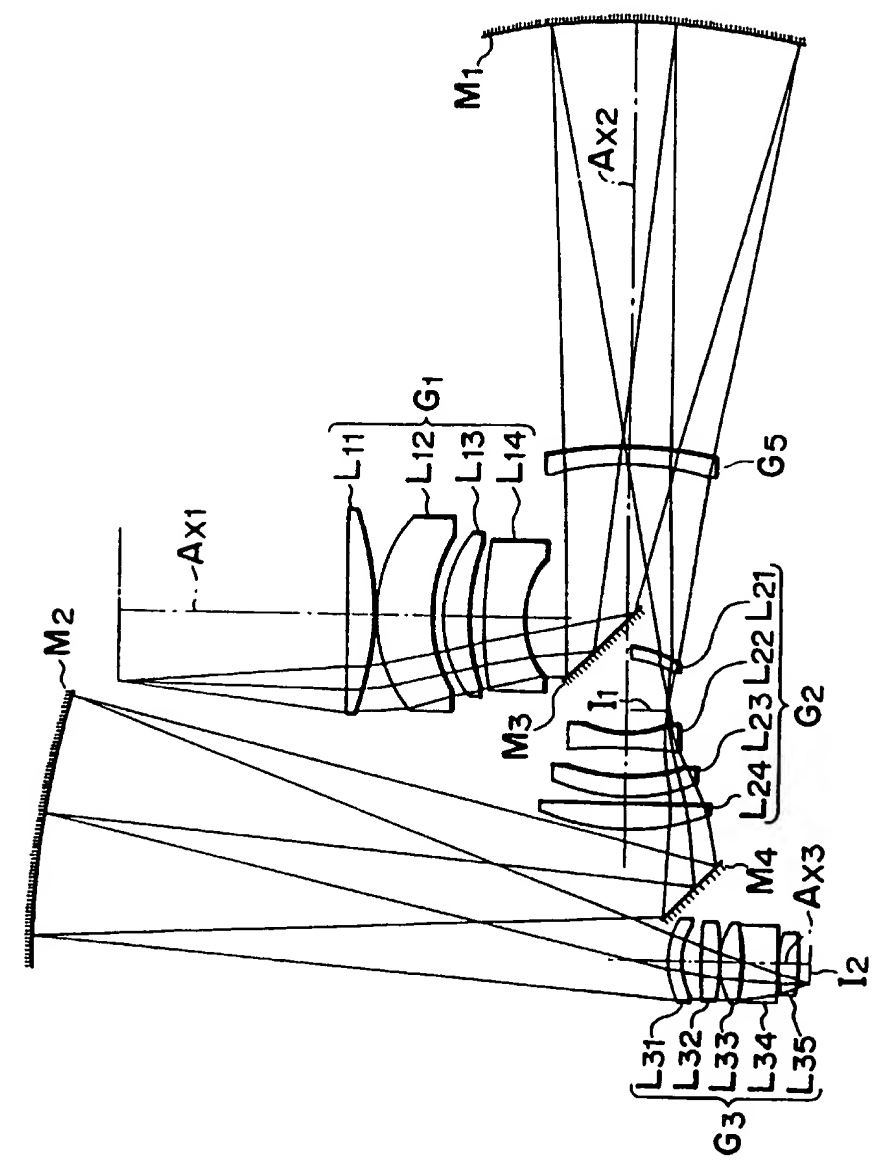

M_1
Ax_2
G_1
L_{11}
L_{12}
L_{13}
L_{14}
Ax_1
G_5
M_2
M_3
L_{21}
L_{22}
L_{23}
L_{24}
G_2
I_1
M_4
Ax_3
I_2
L_{31}
L_{32}
L_{33}
L_{34}
L_{35}
G_3

FIG. 14

COMA

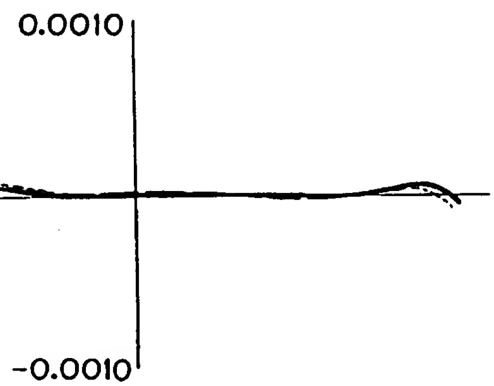


FIG.15

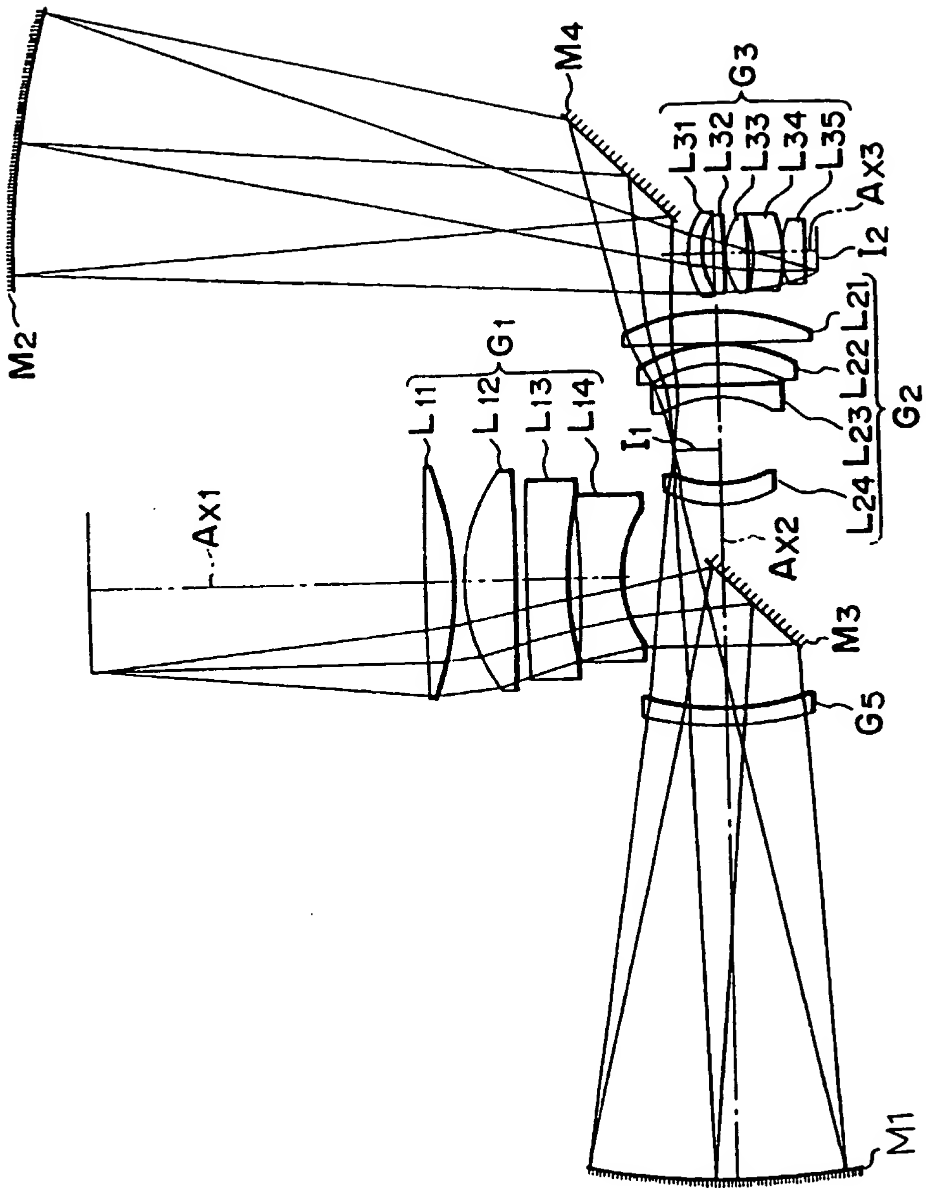

M2
M4
G3
L31
L32
L33
L34
L35
Ax3
I2
L21
L22
L23
L24
G2
I1
Ax2
G1
L11
L12
L13
L14
Ax1
M3
G5
M1

FIG. 16

COMA